PREPARATION AND POLYMERISATION OF UNSATURATED DERIVATIVES OF DI-O-ISOPROPYLIDENE-D-GLUCOFURANOSE

Thesis submitted for the degree of Doctor of Philosophy

by

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INTRODUCTION

General Introduction

Synthetic organic polymers now form an integral part of modern civilisation and their outstanding properties, collectively or separately, are utilised in many diverse ways. Mention can be made of the chemical inertness of poly(vinyl chloride) and of polytetrafluoroethylene, the high tensile strength of nylon, the optical transparency of poly(methyl methacrylate), and the versatility and availability of polyethylene and polypropylene. Partly because of this, new polymers in any particular field must necessarily have exceptional properties before they can be considered suitable for development; this is particularly so amongst synthetic fibres.

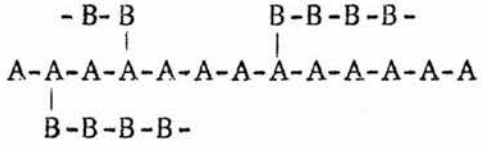
Even in this highly competitive field, however, certain desirable properties are still sought, such as resistance to heat, increased water absorption and improved dyeing properties. In most plastics and synthetic fibres the inherent stability and lack of reactive groups are disadvantageous, with the result that extensive research is being carried out into methods of modifying these unreactive polymers; copolymerisation is the technique most widely used for this purpose, as in the copolymerisation of standard fibre-forming monomers with N-vinyl 2-pyrrolidone, for example, to impart affinity for dyes. Vinyl acetate can also be used for copolymerisation, and subsequent hydrolysis to a poly(vinyl alcohol) copolymer gives hydrophilic properties.

Patent literature indicates that even more work is being done on graft and/...

and block copolymers, where the monomer units do not occur randomly distributed along the polymer chain but in controlled segments. In block copolymers the segments are formed progressively at the ends of the growing polymer molecules:-

-A-A-B-B-B-A-A-A-A-B-B-A-A-

Where A and B are different monomer units. Graft copolymers, on the other hand, have segments of B units attached as branches to the main polymer A-chain:-



Where sufficiently reactive sites do occur along the polymer chains or at the chain ends, such copolymers are easily formed, but in many cases they must be formed <u>in situ.</u> Methods available for creating active centres in the chains include mechanical degradation by physical grinding, the application of shearing forces or ultrasonic irradiation, while electron, gamma, and ultraviolet radiation are also used to activate polymers. Chemical reactions can also be applied; e.g., polyolefine fibres such as polypropylene have been first treated with ozone to promote subsequent grafting with acrylonitrile, which produced graft copolymer fibres with improved tensile strength and dyeing qualities. Peroxidation with hydrogen peroxide is another method employed and others utilise free radical catalysts, such as benzoyl peroxide, or photolytic reactants to give free radicals.

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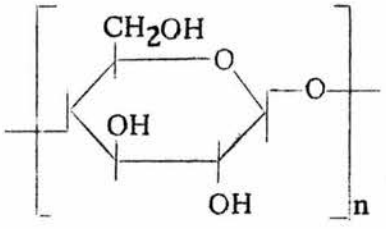
In contrast to the deficiencies of modern synthetic polymers just described, cellulose possesses important properties which have helped cotton to maintain its supremacy in the textile industry despite the growing challenge of man-made fibres. The presence of three free hydroxyl groups on each glucose unit in cellulose



Cellulose

confers useful hydrophilic properties, so that at 65% relative humidity at 25°C cotton absorbs 8% moisture, compared with nylon (4%), poly(ethylene terephthalate) (0.4%) and wool (16%). The effect of hydrogen bonding between hydroxyl groups on adjacent chains has an important bearing on the physical properties of cellulose and especially on its insolubility in water. This can be overcome, however, by suitable solvents such as cuprammonium hydroxide, enabling cotton to react homogeneously in solution, as well as heterogeneously in dispersed form, to give many commercially important cellulose esters and ethers. In contrast to the synthetic polymers, cellulose is readily dyed, and this can be attributed to the large number of reactive sites in the natural polymer.

In certain aspects, however, cellulose fibres compare unfavourably with their purely synthetic counterparts. They do not have such a high tensile strength, in addition to being comparatively inextensible, and their abrasion resistance is less. Furthermore, cellulose is susceptible to attack by micro-organisms./...

organisms. Many specialised bacteria and fungi possess cellulolytic enzyme systems which attack the β-D-glucosyl link between the units in the polymer chain, causing extensive degradation of the long chain molecule.

From a comparison of the properties of synthetic and natural fibres, it is clear that each class possesses individual properties of great merit, but for particular purposes would benefit from borrowing certain properties from the other. It is therefore conceivable that a purely synthetic polymer containing glucose units linked by an addition polymerisation technique might possess interesting intermediate properties. The main objectives of this investigation are to demonstrate that such polymers can be formed and to study some of their chemical and physical properties.

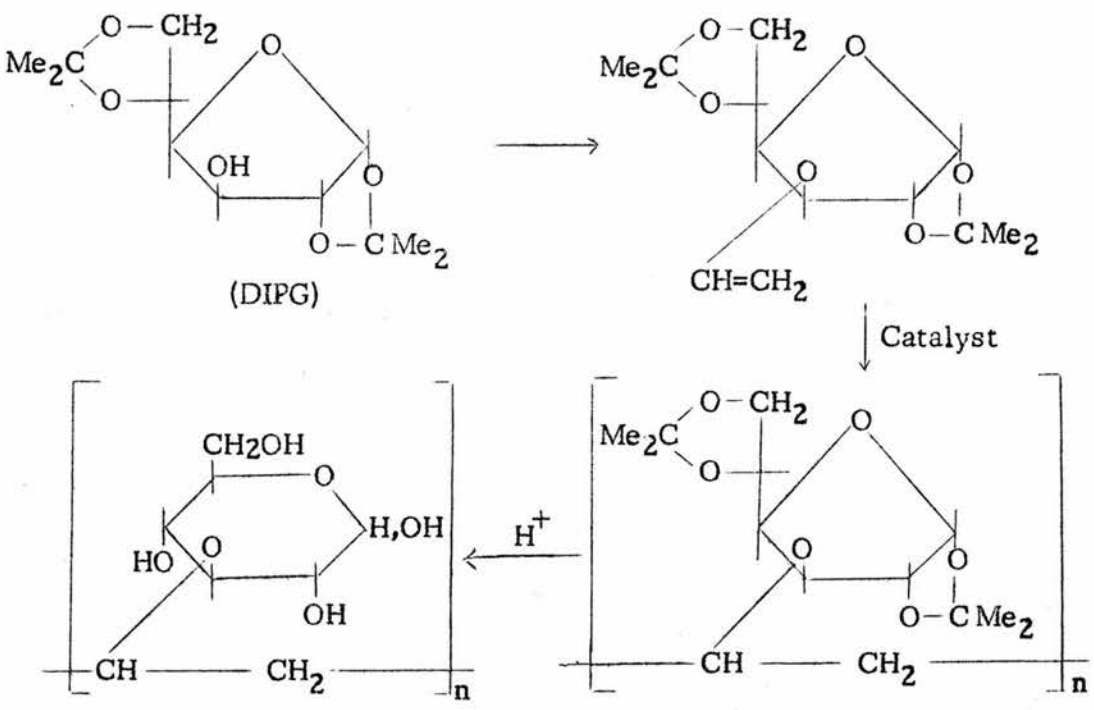
Scope

From the beginning, it was decided to limit the study to vinyl derivatives of hexoses and to consider only monofunctional vinyl derivatives to ensure that purely linear polymers would result, rather than the insoluble and intractable resins that arise when polyfunctional monomers polymerise to form three-dimensional networks. This was particularly important for the preparation of derivatives of the polymers. In turn, this demanded that only one hydroxyl group in the glucose molecule should be available for vinyl group attachment which therefore involved the use of suitably substituted glucose derivatives. After polymerisation, subsequent removal of the blocking groups and production of free hydroxyl groups would then produce a polymer with hydrophilic characteristics/...

characteristics similar to those of wool and cellulose.

Crystalline 1,2:5,6-di-O-isopropylidene-α-D-glucofuranose (DIPG) is ideally suitable as starting material for the preparation of the monosubstituted monomers. It is readily formed in high yield from glucose. Only C(3) has a free hydroxyl group available for the reaction standing exo with respect to the fused system containing the furanose and the 1,2-O-isopropylidene rings. Although this structure is sufficiently stable to allow the molecule to undergo many substitution reactions on C(3), the isopropylidene groups are easily removed by dilute mineral acids or by cation exchange resins. This ease of hydrolysis distinguishes O-isopropylidene ring systems from other similar blocking groups such as O-methylene derivatives, which are comparatively stable to acid.

It was therefore proposed to investigate the introduction of various unsaturated vinyl-type groups into the DIPG molecule at C(3). Polymerisation of these monomers would give rise to linear polymers with a carbon-carbon backbone and a DIPG residue attached to every second carbon atom in the chain; e.g.



Removal of the isopropylidene groups would then give a deacetonated polymer with glucopyranose units containing four free hydroxyl groups on C(1), C(2), C(4) and C(6), and able to react through a free reducing group at C(1).

The chemical and physical properties of such glucose polymers would make interesting comparisons with those of the natural polysaccharides in which C(1) is never free, as it is always involved in the glycosidic linkage between the component monosaccharide units. Similarities exist in the presence of free hydroxyl groups in the glucose moieties which could possibly undergo standard carbohydrate reactions such as etherification, esterification and periodate oxidation. At the same time, important differences arise in that the new structures suggested above have carbon-carbon backbones with glucose residues attached containing free reducing groups. This suggests that a wider range

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of derivatives is possible by including reactions based on the aldehydic groups, such as glycoside formation, oxidation to a poly(gluconic acid) structure and reduction to a polyglucitol derivative. Some of these possibilities have been investigated.

Literature Survey

Currently, a great deal of interest is being shown in synthetic polymers containing monosaccharide moieties, as can be seen from the number of references in the relevant literature. It is noteworthy that in several instances suitable monomers have been synthesised but not polymerised.

Earlier work in this field was mainly concerned with making insoluble cross-linked polymers for use in surface coatings and resins, rather than with well-defined linear polymers; consequently, no special care was taken to control the degree of substitution or the position of the unsaturated groups in the carbohydrate molecule and mixed products resulted. In certain cases complete substitution of all the free hydroxyl groups in the sugar unit was achieved in an effort to gain the highest degree of cross-linking in the final polymer.

Vinyl ethers

It was not until after 1930 that serious attention was first paid to the synthesis of monofunctional, unsaturated sugar derivatives, when the German chemist Reppe and his coworkers investigated the possibilities of making useful polymers from many vinyl compounds, but principally from vinyl ethers/...

ethers, CH_2=CHOR. In a review of vinylation, i.e. the addition reactions of acetylene leading to vinyl derivatives, Reppe et al. (1956) discussed the various methods of synthesising vinyl ethers. Most of the preparations described involved the reaction of a primary or secondary alcohol with acetylene, suitably diluted with nitrogen, in the presence of alkali, such as sodium hydroxide, at moderately high pressure and temperature in a non-aqueous medium:-

$$ROH + CH{\equiv}CH \xrightarrow[\text{ca. } 150°]{NaOH} ROCH{=}CH_2$$

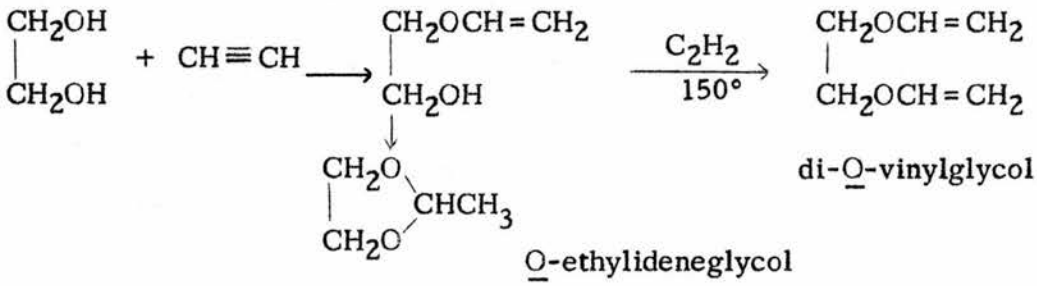
The mechanism is considered to be a nucleophilic attack on acetylene:-

$$ROH + OH^{\ominus} \longrightarrow RO^{\ominus} + H_2O$$

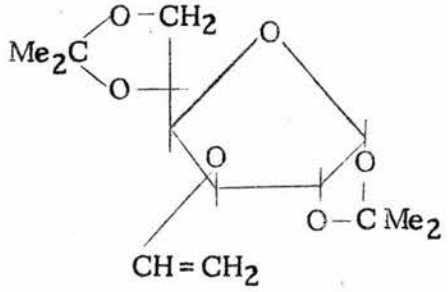
$$RO^{\ominus} + CH{\equiv}CH \longrightarrow ROCH{=}CH^{\ominus}$$

$$ROCH{=}CH^{\ominus} + ROH \longrightarrow ROCH{=}CH_2 + RO^{\ominus}$$

With polyhydroxy compounds, the reaction is complicated by cyclic acetal formation at high temperatures:-



One of the sugar derivatives reported was the 3-O-vinyl ether of DIPG, 1, 2:5, 6-di-O-isopropylidene-3-O-vinyl-α-D-glucofuranose,



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although in impure form, with no details given of its properties or of its polymerisation. In contrast, 2,3:4,5-di-O-isopropylidene-D-fructopyranose was vinylated by the same technique to give a purer product, the 1-O-vinyl ether, which was polymerised with a solution of boron trifluoride dihydrate in dioxan at 0° to a white resinous product, readily soluble in solvents such as benzene, chloroform and acetone. The degree of polymerisation was estimated to be six, while that of a polymerised mixture of the vinyl ethers from both DIPG and diisopropylidene-fructose was even lower (Reppe and Hecht, 1939).

More recently, Mikhant'ev and Lapenko (1957) reported a further preparation of the 3-O-vinyl ether of DIPG, essentially by the application of Reppe's technique, although the method was attributed to Favorskii and Shostakovskii (1943); DIPG in dioxan solution was heated at 150° with acetylene at high pressure in the presence of solid potassium hydroxide to form the ether in 54.5% yield.

Some details were given of its characterisation but no mention was made of polymerisation; instead, reactions of the ether with alcohols and organic acids were investigated (1960). The same authors reported the preparation of the tri-O-vinyl ether from 1,2-O-isopropylidene-α-D-glucofuranose (1957a) and, more recently (1961), the preparation of 1,2:3,4-di-O-isopropylidene-6-O-vinyl-D-galactose in 67% yield by the same procedure.

Shostakovskii and his coworkers prepared the tetra-O-vinyl ether of methyl α-D-glucopyranoside (1954) and the vinyl ethers of cellulose (1956), the latter slowly polymerising in dioxan with boron trifluoride catalyst.

Another/...

Another mono-O-vinyl ether recently described (Deutschman and Kircher, 1961) and fully characterised, was the 2-O-vinyl ether of methyl α-D-gluco-pyranoside, isolated after separation from the isomeric 3-, 4- and 6-O-vinyl ethers. Vinylation of the methyl α-D-glucoside in tetrahydrofuran was achieved either with acetylene in the presence of potassium hydroxide or with vinyl chloride and excess sodium hydroxide, an alternative method of preparation first noted by Reppe (1956).

Acryloyl and methacryloyl derivatives

Acryloyl and methacryloyl derivatives of carbohydrates have been extensively studied, presumably because of their ease of polymerisation by free radical catalysts or even by heating alone in the presence of oxygen.

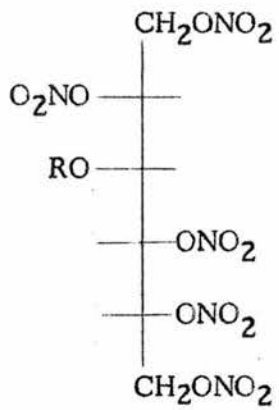
Treadway and Yanovsky (1945) prepared methacrylic esters of several carbohydrates. Glucose, for example, when heated at 65° with methacrylic anhydride in pyridine, formed a pentamethacrylate which gelled in the presence of benzoyl peroxide or copper naphthenate in solution in organic solvents. The derivative became insoluble in organic solvents when it was heated in air at 100° for two hours. Other derivatives reported, all with the same tendency to polymerise, were the fully methacrylated derivatives of maltose, dextrin and starch.

Haworth et al. (1946) formed dimethacrylic and diacrylic esters from various derivatives of D-mannitol and D-glucitol, including the 1,4:3,6-dianhydrides of both hexitols. 2,4:3,5-Di-O-methylene-D-mannitol and

2,4/...

2,4:3,5-di-O-methylene-D-glucitol were also esterified to give unsaturated groups on C(1) and C(6) by treatment in sodium hydroxide solution with methacryloyl or acryloyl chloride. The outstanding feature of these di-esters was their ready polymerisation to form hard, transparent, insoluble resins. Another derivative synthesised and polymerised was methyl 4,6-O-benzylidene-2,3-di-O-methacryloyl-α-D-glucopyranoside. In contrast, 5,6-O-acrylidene-1,3:2,4-di-O-methylene-D-glucitol, a tri-O-cinnamylidene-D-mannitol and diallyl 2,4:3,5-di-O-methylene-D-glucarate failed to polymerise with benzoyl peroxide catalyst.

Interest in nitrated polymers led Wolfrom et al. (1959) to synthesise unsaturated derivatives of D-mannitol pentanitrate:-



where $R = CH_2 = CH - CO -$

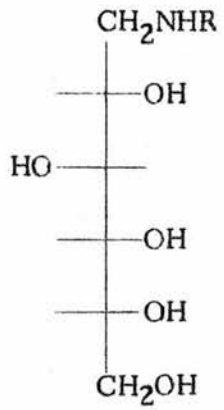
or

$$CH_2 = \underset{\displaystyle CH_3}{\overset{\displaystyle |}{C}} - CO -$$

Reaction with acryloyl chloride in acetonitrile containing N,N-dimethylaniline gave in 72% yield the crystalline 3-O-acryloyl derivative, which polymerised with benzoyl peroxide, but only low molecular weight, gummy polymers were obtained. The syrupy 3-O-methacryloyl derivative, similarly prepared in 40% yield, polymerised to a hard polymer on exposure to light and air.

Whistler, Panzer and Roberts (1961) discussed the advantages of polymers containing/...

containing sugar units attached to every second carbon atom in a hydrocarbon chain and emphasised the commercial importance of synthetic polymers of a hydrophilic nature. Preferring a straight chain sugar to a ring form for this purpose, they synthesised N-acryloyl and N-methacryloyl derivatives of 1-amino-1-deoxy-D-glucitol by N-acylation with the appropriate acid anhydrides in methanol at temperatures below 0°:-



where $R = CH_2 = CH - CO -$

or

$CH_2 = C(CH_3) - CO -$

These authors found that saturated aqueous solutions of the unsaturated amides were polymerised to viscous solutions by ultraviolet and gamma irradiation and to insoluble gels with ammonium persulphate; treatment of the monomers in dimethylformamide solution with azobisisobutyronitrile or benzoyl peroxide catalysts at 60-100° gave high yields of polymer, but high limiting viscosity numbers were obtained only by polymerising concentrated aqueous solutions of the monomers with the redox catalyst system, persulphate-bisulphite, at 0°. Viscous solutions were thus formed, comparable to those of the natural and synthetic gums; addition of sodium borate to such a solution caused it to set to a rigid gel.

Copolymerisation/...

Copolymerisation of both monomers was studied with vinyl acetate, methyl methacrylate and styrene, enabling the appropriate monomer reactivity ratios to be calculated (Whistler and Goatley, 1961). 1-Acrylamido-D-glucitol reacted with amylose in basic lithium chloride solution at 70° in a graft polymerisation experiment, introducing poly(1-acrylamido-1-deoxy-D-glucitol) branches into the amylose molecules (Whistler and Roberts, 1961).

Allyl ethers

Allyl ethers have been fully investigated. This may be due in part to the fact that they can be much more readily formed from the halides than other vinyl compounds, because of the greater reactivity of the halogen atom.

$$ROH + CH_2=CH-CH_2Br \xrightarrow[70\text{-}5^\circ]{50\%NaOH} RO-CH_2-CH=CH_2$$

This direct allylation method was successfully applied by Yanovsky and his coworkers to the synthesis of many allylated carbohydrates. For complete allylation, it was generally necessary to convert the partially allylated ether to the sodium alcoholate and then react the latter with more allyl bromide. The preparations of the fully allylated derivatives of the common sugars and polyhydric alcohols were described, including methyl α-D-glucoside (Nichols and Yanovsky, 1944), D-mannitol, D-glucitol, glycerol, pentaerythritol and sucrose (Nichols and Yanovsky, 1945), and allyl α- and β-D-glucoside and allyl α-D-galactoside (Talley et al., 1945). Fully substituted methallyl ethers ($ROCH_2-\underset{CH_3}{C}=CH_2$) of several of these compounds were also synthesised

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in a similar manner by Nichols et al., (1946) for comparison with the corresponding allyl ethers. Both sets of compounds were polymerised by bubbling oxygen through the liquids at temperatures around 100°, but, in the absence of a catalyst such as cobalt naphthenate, the methallyl ethers gelled much more slowly. Large amounts of benzoyl peroxide (15% or more) were necessary to cause polymerisation of both types of ether at correspondingly high temperatures. Wrigley and Yanovsky (1948) concluded that increasing chain length and increasing degree of allylation reduced the time of gelation.

Anikeeva and Zarubinskii (1958) synthesised the 1-O-allyl and 1-O-methallyl ethers of various diacetals and diketals of xylitol by heating them at 50-70° in a solvent with allyl bromide or methallyl chloride in the presence of powdered sodium hydroxide. It was claimed that the ether was formed in each case at the primary carbon atom. No polymerisations were recorded.

The preparation of monoallyl ethers was reviewed by Bladon and Owen (1950), who were concerned with the use of monoallyl D-mannitol and D-glucitol derivatives as intermediates in the preparation of mercaptopropanol derivatives. The properties of the monoallyl ether of DIPG, 3-O-allyl-1,2:5,6-di-O-isopropylidene-α-D-glucofuranose, were reported by Corbett and McKay (1961), who prepared it by treating DIPG with allyl bromide and powdered sodium hydroxide in dioxan at 45°. The 3-O-allyl ether of D-mannitol pentanitrate was prepared by Wolfrom et al. (1959), but could not be polymerised. It is noteworthy that no instance of the successful polymerisation

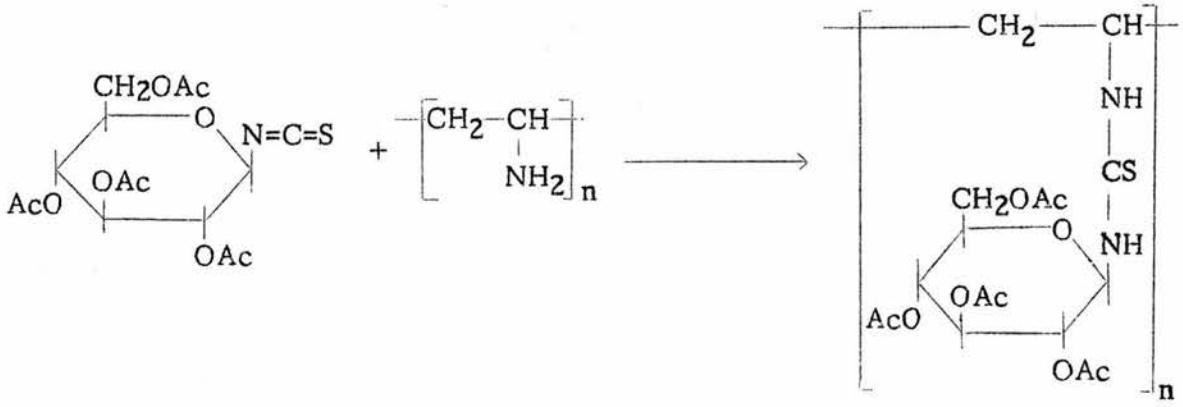
of/...

of a carbohydrate monoallyl ether has been reported.

Miscellaneous monomers and polymers

An interesting development was the synthesis by Helferich and Höffman (1952) of p-hydroxystyrene β-D-glucoside from p-ethyl phenyl tetra-O-acetyl-β-D-glucoside. Ultraviolet irradiation of the monomer with or without benzophenone in dioxan or heating with benzoyl peroxide caused polymerisation. Treatment of the monomeric β-D-glucoside with an emulsin solution or with dilute hydrochloric acid caused scission, whereas the water-soluble polymer was unaffected by emulsin, but was split by acid. From emulsin solution β-D-glucosidase was specifically absorbed on poly(p-hydroxystyrene β-D-glucoside) and β-D-galactosidase was similarly absorbed on poly(p-hydroxystyrene β-D-galactoside) (Helferich and Jung, 1958).

Micheel and Himmelmann (1955) also synthesised a carbon-chain polymer with glucose residues attached, in this case through thiourea groups, by reacting poly(vinylamine) with tetra-O-acetyl-β-D-glucose 1-isothiocyanate:-



Saponification of the acetyl groups converted the polymer to a water-soluble form. Other modified polymers were formed from poly(vinylamine) and β-D-glycosylisothiourea S-ethyl ether, poly(vinylamine) and free glucose, giving a poly(N-saccharide), and poly(vinyl alcohol) and acetobromoglucose, giving a poly(O-glucoside).

Two other interesting monomers were recently described in the literature. Burton et al., (1961) recorded the preparation of a C-vinyl compound, methyl 3,4-O-isopropylidene-2-C-vinyl-β-L-erythropentoside, from the reaction of vinyl magnesium bromide in tetrahydrofuran with methyl 3,4-O-isopropylidene-2-oxo-β-L-erythropentoside, an oxo-derivative of arabinose. Wolfrom et al., (1961) reported the preparation of the 3-O-vinylcarbamoyl derivative (p. 11) (R = CH_2=CHNHCO—) of D-mannitol pentanitrate using vinyl isocyanate in acetonitrile. In neither case was polymerisation discussed.

Mention should also be made at this point of the considerable volume of research being carried out on synthetic polysaccharides formed directly from monosaccharide units, reviewed recently by Pogosov and Rogovin (1961). While these do not come under the scope of this investigation, some have been formed by an epoxide polymerisation, another form of addition polymerisation. From this aspect is is worth noting the work of Schuerch and his coworkers on the acid-catalysed polymerisation of 1,6-anhydro-β-D-glucopyranose (Carvalho, Prins and Schuerch, 1959) and 1,6-anhydro-β-D-galactopyranose (Battacharya and Schuerch, 1961). The latest paper (Nevin, Sarkanen and Schuerch, 1962) on the/...

the basic polymerisation of 5,6-anhydro-3-O-methyl-1,2-O-isopropylidene-D-glucofuranose bears a stronger resemblance to the topic of this thesis, since the resulting low-molecular weight polymer was oxidised to a poly(gluconic acid) derivative at C(1) after hydrolysis of the isopropylidene groups. Mora and his coworkers have also been active in chemical modifications of synthetic "polyglucoses" prepared by acid-catalysed polycondensation of α-D-glucose. Preparations of "polyglucose" sulphates (Wood and Mora, 1958) and carboxyl derivatives (Mora, Merler and Maury, 1959) have been described.

Note:- A paper published recently by Kimura and Imoto (1961) embodies a large part of the earlier findings of this thesis. As its date of publication is more than a year later than that of a preliminary note (Bird et al., 1960) announcing some results of this study, it is not proposed to review this paper, although reference will be made to it at appropriate places in the text.

EXPERIMENTAL

I. 1,2:5,6-Di-O-isopropylidene-3-O-methacryloyl-α-D-glucofuranose

Materials

1,2:5,6-Di-O-isopropylidene-D-glucofuranose (DIPG). This was prepared from glucose by Bell's method (1935). L. Light and Co. Ltd. reagent, recrystallised from light petroleum (b.p. 60-80°), was also used. M.p. 109-109.5°; $[\alpha]_D^{20}$ -18.5° in water (c, 2.63).

Methacrylic anhydride. Borden Chemical Co. (Philadelphia, U.S.A.) reagent, stabilised with 0.1% hydroquinone-tetrabromohydroquinone.

Methacryloyl Chloride. Borden Chemical Co. reagent, redistilled (b.p. 99°) immediately before use.

Benzoyl Peroxide. Polymer Consultants Ltd. reagent, recrystallised from chloroform-methanol.

Ammonia. Imperial Chemical Industries anhydrous grade, dried by condensing over sodium hydroxide pellets immediately before use.

Lithium, potassium and barium metals (Hopkin and Williams) were washed with light petroleum (b.p. 30-40°), clean surfaces exposed by cutting under light petroleum immediately before use and the metal dried and weighed under nitrogen in a stoppered container.

Azobisisobutyronitrile. Polymer Consultants Ltd. reagent, recrystallised twice from ethanol, m.p. 103°.

sym.-Tetrachloroethane. British Drug Houses technical reagent was purified by washing four times with concentrated sulphuric acid on a steam-bath with stirring, followed by steam distillation, drying firstly over potassium carbonate then over calcium chloride, and finally by distillation from a water-bath under reduced pressure to keep the b.p. below 60°. DIPG had a constant rotation ($[\alpha]_D^{26}$ -10.0°; c, 2) in this purified solvent. Attempted purification by distillation at atmospheric pressure through a Widmer column caused extensive decomposition and liberation of hydrogen chloride which hydrolysed isopropylidene residues in DIPG and its derivatives.

Benzene. "Analar" reagent dried over sodium wire and redistilled from phosphorus pentoxide.

Methyl methacrylate. British Drug Houses reagent was redistilled immediately before use and was employed without inhibitor.

Sodium chlorite. British Drug Houses technical reagent was recrystallised from a filtered 50% aqueous solution.

Methyl iodide. Hopkin and Williams general purpose reagent redistilled from sodium wire using a Widmer column and the fraction b.p. 41.5° collected.

General Methods

Elementary analyses were carried out by A. Bernhardt, Mülheim, Germany.

Infrared spectra were measured with a Perkin-Elmer "Infracord" 137.

Specific rotations were measured in a 2 dm. tube, in tetrachloroethane (unless otherwise stated) at a concentration, c, of 0.5 g./100 ml.

Polymer melt temperatures (P. M. T.) and melting points of crystalline compounds were recorded on a Kofler block.

Inherent viscosity, $[\eta] = c^{-1} \ln (\eta_{solution}/\eta_{solvent})$, was determined at 25° in tetrachloroethane (unless otherwise stated) in an Ostwald viscometer at a concentration, c, of 0.5 g./100 ml. Results are expressed in decilitres/gram.

The acetyl content of poly(1, 2, 4, 6-tetra-O-acetyl-3-O-methacryloyl-D-glucose) was determined by treating the acetate (20 mg.) with excess sodium hydroxide solution (10 ml.) at 0° for several hours and then titrating excess alkali with 0.1 N sulphuric acid with phenolphthalein as indicator.

The nickel content of 3-O-methyl-D-glucitol was determined with dimethylglyoxime reagent.

Paper partition chromatography was carried out on Whatman No. 1 paper (descending development):-

Solvent system A:- n-Butanol:ethanol:water - 40:11:19.

Unless otherwise stated, percentage concentrations are expressed on a weight/volume (w/v) basis.

Preparation of 1,2:5,6-Di-O-isopropylidene-3-O-methacryloyl-α-D-glucofuranose (DIPG methacrylate).

(a) With pyridine and methacrylic anhydride

A solution of DIPG (20 g.) in dry pyridine (100 ml.) was heated at 65° for 3.5 hr. with methacrylic anhydride (20 ml.); water (50 ml.) was then added and the mixture was heated with stirring at 65° for 1 hr. After standing overnight at 30°, the reaction mixture was extracted with light petroleum (b.p. 30 - 40°; 3 x 100 ml.) and the extract was washed with 5% sodium hydroxide solution (3 x 100 ml.) and water. The extract was dried (sodium sulphate) and tetrachlorohydroquinone (20 mg.) added to it before concentration under reduced pressure to a syrup which was twice distilled in vacuo to give a colourless, viscous syrup, 1,2:5,6-di-O-isopropylidene-3-O-methacryloyl-α-D-glucofuranose in 50-70% yield from different preparations; b.p. 120°/0.2 mm.; n_D^{18} 1.4614; $[\alpha]_D^{25}$ - 37.0° in ethanol, - 40.0° in chloroform, - 32.2° in tetrachloroethane (c, 1).

Found: C, 57.9; H, 7.13; methacryloyl (by saponification), 19.7. $C_{16}H_{24}O_7$ requires C, 58.5; H, 7.37; $CH_2{:}C(CH_3)CO$, 21.0%.

The derivative showed no OH absorption at 3400 cm^{-1} in the infrared but had $\nu_{max.}$ (cm^{-1}): 3000 (C-H), 1735 (ester C=O), 1370, 1215, 1160, 1080, 1030, 950, 890, 850 (film between sodium chloride plates; Appendix I).

The syrup slowly crystallised, on keeping at 0° for several weeks, to form platelets, m.p. 34-5°.

(b)/...

(b) With pyridine and methacryloyl chloride

A solution of DIPG (10.05 g.; 38.6 mmol.) in dry pyridine (50 ml.) was heated at 65° for 3.5 hr. with methacryloyl chloride (6.5 ml.; 54 mmol.). Water (25 ml.) was added and, after standing overnight at 30°, the solution was extracted with light petroleum (b.p. 30-40°; 3 x 25 ml.). The extract was dried (sodium sulphate), tetrachlorohydroquinone (10 mg.) added, solvent removed under reduced pressure and the resulting syrup distilled in vacuo to give the ester (4.17 g.; 32.9%), which was identical to that described under (a).

(c) With the 3-potassio salt of DIPG and methacryloyl chloride

DIPG (10.08 g.; 38.7 mmol.), dissolved in hot light petroleum (b.p. 60-80°; 100 ml.), was heated with vigorous stirring at 70° for 3 hr. during which pieces of potassium (total 1.512 g.; 38.7 m-atom) were added gradually to the solution; an atmosphere of dry, oxygen-free nitrogen was maintained in the system. Methacryloyl chloride (4.025 g.; 38.5 mmol.) in light petroleum (b.p. 60-80°; 10 ml.) was then added dropwise over 1 hr. to the stirred solution kept at 60°. The resulting white precipitate (4.60 g.) was filtered and found to contain 2.556 g. (88.6%) of potassium chloride. The filtrate was concentrated and the syrup fractionally distilled in the presence of hydroquinone inhibitor, the fraction boiling at 114-120°/0.14 mm. being the methacrylate ester (6.00 g.; 47.2%).

Attempted/...

Attempted Deacetonation of 1,2:5,6-Di-O-isopropylidene-3-O-methacryloyl-α-D-glucofuranose

(a) With 0.5 N sulphuric acid at 100°

The ester (102.8 mg.) was hydrolysed with 0.5 N sulphuric acid (5 ml.) for 3 hr. at 100°, the solution neutralised with sodium hydroxide solution (15%) using phenol red indicator, and the sodium sulphate precipitated with ethanol (75 ml.) and centrifuged. The resulting ethanolic solution was concentrated under reduced pressure to a glass (81.1 mg.), which contained glucose only by chromatography in solvent system A with aniline hydrogen phthalate spray.

(b) With 0.01 N sulphuric acid at 100°

The ester (235 mg.) was treated with 0.01 N sulphuric acid (10 ml.) at 100° for 6 hr., neutralised with sodium hydroxide solution (0.05 N) to phenol red and worked up as before to a glassy syrup (170 mg.). Chromatography in solvent system A (aniline hydrogen phthalate spray) showed that the syrup contained glucose (R_f 0.18) and two other reducing components (R_f 0.40, 0.67). Both aniline hydrogen phthalate and benzidine-trichloroacetic acid sprays failed to detect DIPG and 1,2-mono-O-isopropylidene-α-D-glucofuranose.

Preliminary Experiments on the Polymerisation of 1,2:5,6-Di-O-isopropylidene-3-O-methacryloyl-α-D-glucofuranose

(a) Bulk polymerisation

Monomer (507.4 mg.) and benzoyl peroxide (5.1 mg.) were introduced into/...

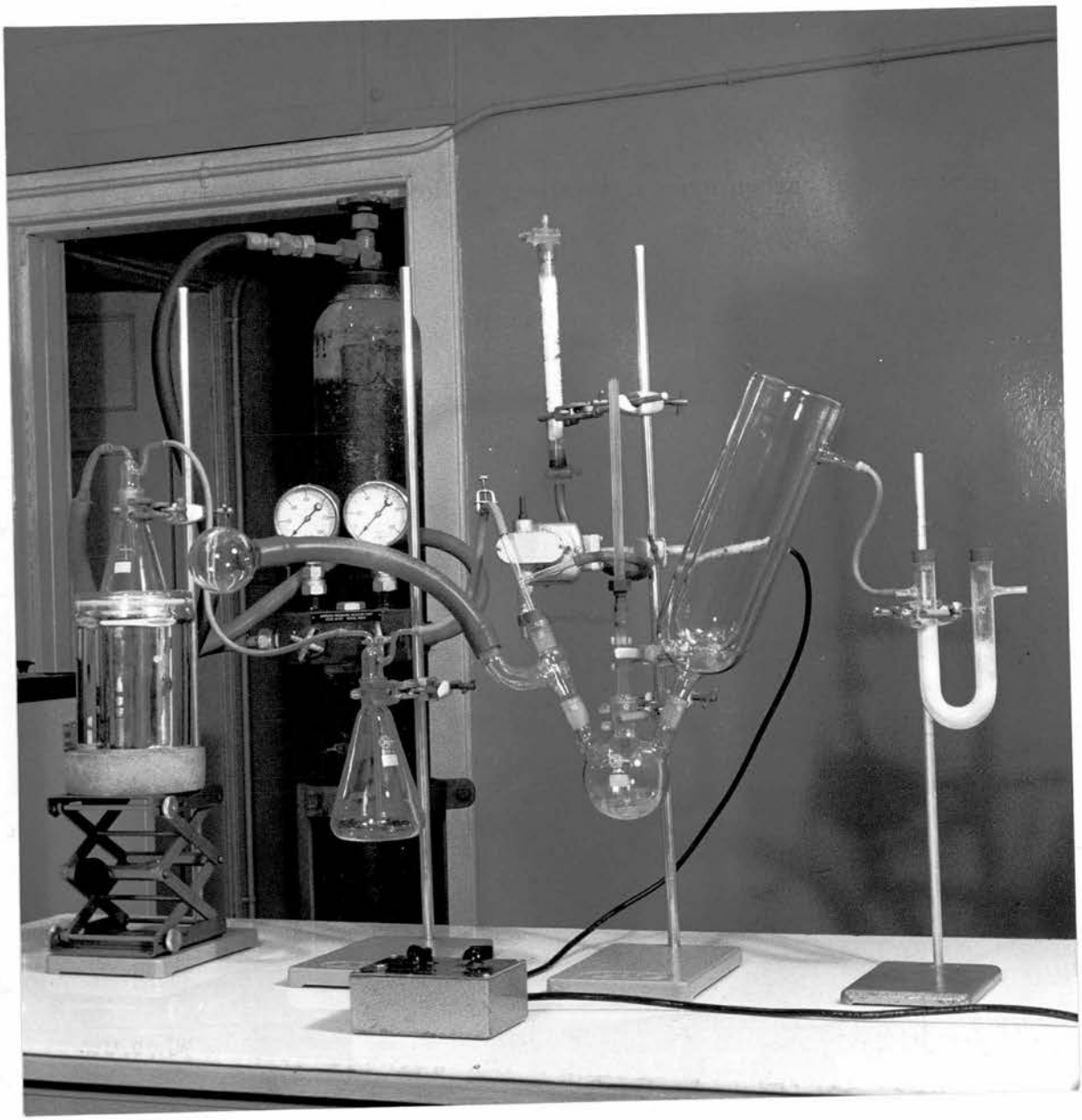
into a tube which was sealed after thorough flushing with nitrogen. On heating at 60° for 2 hr., the monomer showed an appreciable increase in mobility and the catalyst, hitherto dispersed throughout the liquid medium, settled out in the bottom of the tube without dissolving. When the temperature was raised to 80°, an increase in viscosity was noted after 15 mins. The material at the bottom of the tube solidified first (1 hr.) and the contents had completely solidified after 4 hr. A hard, transparent plug was obtained after smashing the tube; the polymer was insoluble in refluxing chloroform and in other common solvents.

(b) Solution polymerisation in benzene with free radical catalysts

A standard procedure was followed for all the polymerisation experiments summarised in this section: monomer (100 mg.), catalyst and solvent (benzene) were introduced into small glass tubes which were then degassed four times, filled with oxygen-free nitrogen twice, sealed and placed in a constant-temperature bath at 80° $\pm$ 0.1 for benzoyl peroxide-catalysed systems or at 70° $\pm$ 0.1 for azobisisobutyronitrile-catalysed systems. The contents were shaken briefly at the outset to ensure homogeneous solution. After a given time the tubes were removed from the bath, cooled rapidly, opened and the contents diluted with an equal volume of benzene before being poured into excess methanol for precipitation. The polymer was filtered, washed thoroughly with methanol and dried. Results are recorded in Tables 1-3.

(c) Anionic polymerisation with metal amides in liquid ammonia

Polymerisations were carried out in an apparatus designed for the preparation/...



Apparatus for reactions in liquid ammonia.
(Arni et al. 1959)

preparation of carbohydrate derivatives in liquid ammonia (Arni et al., 1959). The metal (0.2 - 4.0 m-atom) and ferric nitrate nonohydrate (7 mg.) in anhydrous liquid ammonia (100 ml.) were stirred at -33° until the blue colour disappeared and a suspension of the insoluble, white, metal amide was formed. Methyl methacrylate (1 ml., ca. 945 mg.; 9.45 mmol.) was then added to the stirred amide suspension, when polymerisation occurred immediately. After the reaction mixture had been stirred for 30 min., ammonium chloride (0.5 g.) was added and the ammonia was allowed to evaporate off under anhydrous conditions. The residue was extracted with boiling benzene (2 x 20 ml.), the centrifuged extracts concentrated under reduced pressure to a small volume, and the polymer precipitated with methanol (50 ml.). The pale yellow solid was filtered, washed successively with methanol and water, and dried.

The same procedure was used for DIPG methacrylate. The monomer (1 g., 3.05 mmol.) was added to the stirred amide suspension, when the monomer rapidly dissolved in liquid ammonia to form a green solution, changing to brown on the addition of ammonium chloride. After the polymer had been isolated as before (washing with methanol only), the benzene-methanol filtrate from the precipitation procedure was concentrated under reduced pressure to a brown syrup, which was extracted with boiling light petroleum (b.p. 60-80°; 2 x 25 ml.). The cooled extracts yielded crystalline DIPG (m.p. and mixed m.p. 109-110°), which was filtered and isolated.

Large-scale/...

Large-scale Preparation of Poly(1, 2:5, 6-di-O-isopropylidene-3-O-methacryloyl-α-D-glucofuranose).

A quantity (53.7 g.) of the methacrylate monomer prepared by the pyridine and methacrylic anhydride method (p. 21) was further purified by washing a solution of the monomer in light petroleum (b.p. 30-40°; 200 ml.) with 100 ml. portions of 5% sodium hydroxide solution until the wash liquor stayed colourless, drying (sodium sulphate), and concentrating under reduced pressure to a syrup which was twice distilled under high vacuum (b.p. 106-8°/0.10 mm.) in the presence of tetrachlorohydroquinone (0.1%). The purified monomer (40.84 g.) was polymerised in benzene (41 ml.) solution by heating at 70° ± 0.1 for 24 hr. in the presence of azobisisobutyronitrile (408 mg.) in a closed flask which had been degassed four times and flushed with oxygen-free nitrogen twice. More benzene (41 ml.) was then added and the polymer was precipitated by pouring the viscous solution into methanol (2 l.) with stirring. The white solid (32.57 g., 79.8% conversion) was centrifuged, washed thoroughly with methanol and dried. It was redissolved in boiling benzene (80 ml.) and reprecipitated in methanol (2 l.) to give poly(1, 2:5, 6-di-O-isopropylidene-3-O-methacryloyl-α-D-glucofuranose) as a white powder (31.21 g., 76.4%). $[\eta]$ 0.50. $[\alpha]_D^{27}$ -47.6 (c, 0.5). P.M.T. 198-202°.

Found: C, 58.3; H, 7.35 $(C_{16}H_{24}O_7)_n$ requires C, 58.5; H, 7.37%. Infrared analysis (KBr disc) showed $\nu_{max.}$ (cm^{-1}): 3000 (C-H), 1740 (ester C=O), 1450, 1380, 1255, 1215, 1160, 1080, 1030, 960, 890, 850. (Appendix I).

Preliminary Experiments on the Deacetonation of Poly(DIPG methacrylate)

(a) Neutralising with anion-exchange resins

(i) Acetonated polymer [52.2 mg.; η, 0.15; $[\alpha]_D$ - 50° in chloroform (c, 0.981)] was hydrolysed with N hydrochloric acid (2 ml.) at 100° in a sealed tube for 17 hr. The resulting pale brown solution was neutralised with Amberlite resin IR-45-OH, filtered, and together with the resin washings, concentrated under reduced pressure to small volume (ca. 2 ml.), which was poured into methanol (30 ml.). The precipitate was centrifuged, washed with ether and dried, forming a white powder (20.3 mg., 51.4% yield). $[\alpha]_D^{23}$ + 47° in water (c, 0.590). The product darkened on heating above 18.5° but did not melt.

(ii) Acetonated polymer (96.1 mg.; η 0.22; $[\alpha]_D$ - 49°) was heated with N hydrochloric acid (10 ml.) at 100° and the hydrolysis was followed polarimetrically until the rotation was constant (2 hr.; α_D + 0.25° in 1 dm. tube); insoluble material was filtered, washed with water and dried (29.1 mg.; 30.3%). A larger quantity (2.494 g.) was then hydrolysed at 100° for 2 hr. with N hydrochloric acid (100 ml.), the acid removed with Amberlite resin IR-45-OH and insoluble material, including resin, was centrifuged and washed with water. The centrifugate and washings were concentrated under reduced pressure to a glass (1.01 g.) which was dissolved in water (20 ml.) before precipitation with ethanol (113 ml.; $\longrightarrow$ 85% v/v solution). The precipitate was centrifuged, washed with ethanol and ether, and dried to a white powder (0.665 g.; 50.6% yield/...

yield, after correction for 30.3% insoluble starting material) $[\alpha]_D^{24}$ + 45° in water (c, 0.497) $[\eta]$ 0.17 in water.

A sample of this polymer was found to have an approximate molecular weight (M) of 43,000 as determined by viscosity and sedimentation measurements, the latter from a Spinco Model E ultracentrifuge, applied to the equation of Mandelkern and Scheraga:-

$$M = \left[\frac{N\eta_0}{\beta(1 - \bar{V}\rho)}\right]^{\frac{3}{2}} S_0^{\frac{3}{2}} [\eta]^{\frac{1}{2}}$$

where N = Avogadro's number, η_0 = viscosity of the solvent in poises, β = constant, depending on shape of molecule, $\bar{V}$ = partial specific volume, ρ = density ($\bar{V}\rho$ was assumed to be ~0.60), S_0 = sedimentation coefficient at infinite dilution, $[\eta]$ = limiting viscosity number (ml./g.).

(b) Neutralising with alkali before dialysis

A portion (997 mg.) of the main sample of acetonated polymer (p. 26) was hydrolysed with N hydrochloric acid (20 ml.) at 100° for 2 hr. with rapid stirring. Insoluble gel was removed by centrifuging, the solution neutralised with 2 N sodium hydroxide solution (methyl orange indicator), dialysed against tap-water overnight and evaporated under reduced pressure to a glass (566 mg.; 75.1% yield). The insoluble gel was washed with water, ethanol and ether, and dried to a white solid (231 mg.; 23.2% based on the weight of acetonated polymer used). The water-soluble glass (566 mg.) was dissolved in water (10 ml.), the solution added dropwise to ethanol (67 ml.) with stirring, and the precipitate/...

precipitate centrifuged, washed with ethanol and ether, and dried to a white powder (526 mg.; 69.8% yield) which was strongly reducing to Fehling's solution. $[\alpha]_D^{22}$ + 54° in water (c, 0.525). $[\eta]$ 0.53 in water.

Large-scale Preparation of Poly(3-O-methacryloyl-D-glucose)

A much larger quantity (20 g.) of poly(DIPG methacrylate) was heated with N hydrochloric acid (400 ml.) at 100° for 2 hr. with rapid stirring while acetone was allowed to escape. Insoluble gel was centrifuged off, washed with water (3 x 200 ml.) and the combined solution and washings neutralised with 4 N sodium hydroxide solution to methyl red. After overnight dialysis against tap-water, the solution was filtered through kieselguhr before concentration under reduced pressure to a smaller volume (100 ml.) and poured into ethanol (670 ml.). The deacetonated polymer, poly(3-O-methacryloyl-D-glucose), was centrifuged, washed with ethanol and ether and isolated as a white powder (9.74 g., 64.4%). $[\alpha]_D^{23}$ + 50° in water (c, 0.523). $[\eta]$ 0.42 in water. The product darkened on heating above 185° but did not melt; it was strongly reducing to Fehling's solution.

Found: C, 48.1; H, 6.39. $(C_{10}H_{16}O_7)_n$ requires C, 48.4; H, 6.50%.

The insoluble gel was rehydrolysed and worked up as before to give a second batch of deacetonated polymer (1.47 g., 9.7%; total yield 74.1%). The residue was finally washed with water, ethanol and ether and dried to a white solid (3.13 g., 15.6% of weight of acetonated polymer).

Reducing/...

Reducing Power of Deacetonated Polymer

(a) With sodium hypoiodite (Hirst et al., 1949).

An aqueous solution (5 ml.) of the deacetonated polymer (2 mg.) was treated with 0.1 N iodine solution (1 ml.) followed by 0.2 M sodium bicarbonate-sodium carbonate solution (2 ml.; pH 10.6) in a stoppered boiling-tube sealed with a little 10% potassium iodide solution. After 2 - 2.5 hr., the solution was diluted to 25 ml., acidified with 2 N sulphuric acid (5 ml.), and the liberated iodine titrated with 0.01 N sodium thiosulphate solution. The difference between this titre and that of a blank with water (5 ml.) was used to calculate the reducing power, which was 94.5% of the theoretical value based on a poly(3-O-methacryloyl-D-glucose) structure. Corresponding figures for D-glucose and 3-O-methyl-D-glucose were 101.2 and 97.3% respectively.

(b) With Somogyi copper reagent (Somogyi, 1952)

An aqueous solution (5 ml.) of deacetonated polymer or standard sugar (1.5 mg.) and Somogyi (1952) copper reagent (5 ml.) were heated in a boiling tube at 100° for 15 min., when the solution was immediately cooled to 30°, 2.5% potassium iodide solution (2 ml.) and N sulphuric acid (5 ml.) added, and the liberated iodine titrated with 0.005 N sodium thiosulphate solution. Results for the polymer, D-glucose and three mono-O-methyl ethers of D-glucose are recorded below. Reduction equivalents are expressed on a molar basis, i.e. as ml. of 0.005 N thiosulphate per 0.005 mmol. sugar or m-equiv. of polymer, and reducing powers are calculated as a percentage of that of D-glucose (Table 5, p. 86).

Preparation/...

Preparation of 3-O-Methyl-D-glucitol

3-O-Methyl-D-glucose was prepared essentially by the method of Glen et al. (1951). DIPG (20 g.) and powdered sodium hydroxide (8 g.) were dissolved in dry acetone (20 ml.), dimethyl sulphate (11 ml.) added slowly and the mixture heated at 45-60° for 6 hr. Water (100 ml.) was added and the resulting suspension was extracted with light petroleum (b.p. 60-80°; 3 x 40 ml.). After being dried (sodium sulphate), the extracts were concentrated at reduced pressure to an amber-coloured syrup (21.65 g.) which was fractionally distilled to remove unreacted DIPG. The main fraction (17.53 g.) was deacetonated with Amberlite resin IR-120-H (5 g.) in water (20 ml.) at 100° for 4 hr., the solution filtered to remove resin, and the filtrate and aqueous washings decolourised with charcoal before concentration to a syrup by repeated evaporation under reduced pressure with ethanol. Crystallisation from methanol (9 ml.) afforded 3-O-methyl-D-glucose (7.964 g., 39.6% yield from DIPG). The derivative was found to be chromatographically pure in solvent system A, using benzidine-trichloroacetic acid spray (R_f 0.36; $R_{glucose}$ 1.52).

Found: C, 43.0; H, 7.38; OMe, 16.4. Calc. for $C_7H_{14}O_6$: C, 43.3; H, 7.27; OMe, 16.0%.

The sugar was reduced with hydrogen and Raney nickel (Dr. L. Hough, personal communication). 3-O-Methyl-D-glucose (997 mg.) was heated under/...

under reflux for 3 hr. with Raney nickel (settled volume, 38 ml.) in 70% ethanol (500 ml.) with hydrogen bubbling through the mixture. The nickel was centrifuged, washed with boiling 50% ethanol (3 x 200 ml.) and the combined ethanolic solutions concentrated at reduced pressure, treated with charcoal and repeatedly evaporated under reduced pressure with ethanol to a green glassy syrup (765 mg.).

Found: OMe, 10.75; Ni, 10.3. Calc. for $C_7H_{16}O_6$: OMe, 15.8%.

The syrup (700 mg.) was deionised by successive treatment with Amberlite resins IR-120-H and IRA-401-OH, and the treated solution was concentrated at reduced pressure to give 3-O-methyl-D-glucitol as a pale yellow syrup (376 mg., 40.8%) $[\alpha]_D^{22}$ + 0.9° in water (c, 3.76).

Found: OMe, 16.6. Calc. for $C_7H_{16}O_6$: OMe, 15.8%.

Chromatography of the syrup in solvent system A with silver nitrate spray revealed only a single spot (R_f 0.34; $R_{rhamnose}$ 0.82) identical to that of an authentic sample.

Preparation of Poly(3-O-methacryloyl-D-glucitol).

Poly(3-O-methacryloyl-D-glucose) (79.7 mg.) in water (8 ml.) was treated with sodium borohydride (25.6 mg.) at 20° and the reaction was followed polarimetrically:- $[\alpha]_D$ + 15° (1 hr), + 5.5° (2.5 hr.), + 4° (5 hr.), +3.5° (23 hr., constant). The solution was then made slightly acid with 2 N acetic acid, concentrated at reduced pressure to 5 ml. and poured into ethanol (28 ml.). The precipitate was centrifuged, washed with ethanol and ether and/...

and dried to a white powder (61.4 mg., 76.5% yield), which was non-reducing to Fehling's solution.

Oxidation of Poly(3-O-methacryloyl-D-glucose) with Chlorous Acid (Davidson and Nevell, 1955).

Deacetonated polymer (29.5 mg.) in an aqueous solution (10 ml.) containing 4 M acetic acid (5 ml.) and M sodium chlorite solution (4 ml.) was kept at 20° in the dark for 24 hr. The solution was treated with Amberlite resin IR-120-H (5 ml.) to remove sodium, the filtrate and washings poured into ethanol (300 ml.), and the precipitated acid washed thoroughly with ethanol and ether and dried (25.5 mg., 81.2%). The polyacid contained 83.7% of the theoretical carboxyl content, determined by dissolving the material in excess 0.01 N sodium hydroxide solution, shaking for 30 min., and back-titrating with 0.01 N sulphuric acid using phenolphthalein indicator. It was non-reducing.

The oxidations of D-glucose, 3-O-methyl-D-glucose, and poly(3-O-methacryloyl-D-glucose) with the above chlorous acid solution, i.e. 0.4 M and 2 M with respect to sodium chlorite and acetic acid respectively, were followed polarimetrically at 20°:-

Time (hr.)	0.25	0.5	1.5	2.0	4.0	22
$[\alpha]_D$: D-Glucose	+56°	-	-	21°	17°	14°
3-O-Methyl-D-glucose	+60	45	27	23	20	14
Poly(3-O-methacryloyl-D-glucose)	+ 46	37	23	20	12	0

Preparation/...

Preparation of Poly(3-O-methacryloyl-D-gluconic acid)

Poly(3-O-methacryloyl-D-glucose) (508.5 mg.) was dissolved in 4 M acetic acid (25 ml.), M sodium chlorite solution (20 ml.) added and the solution diluted to 50 ml. After standing in the dark at 20° for 26 hr. ($[\alpha]_D^{20}$ + 2.0°; constant), the solution was dialysed against tap-water overnight to remove excess chlorite, chlorine dioxide and acetic acid, concentrated under reduced pressure to a small volume, passed through an Amberlite resin IR-120-H column (10 ml.) to remove cations and the eluate and washings freeze-dried to give poly(3-O-methacryloyl-D-gluconic acid) as a non-reducing white solid (491 mg., 90.7%).

Found: COOH, 83.2% of the theoretical value.

Preparation of Salts of Poly(3-O-methacryloyl-D-gluconic acid)

The polymer acid (98.7 mg.) was treated with 0.01 N sodium hydroxide solution (50 ml.) for 2 hr., the excess alkalinity for the most part destroyed with 0.01 N sulphuric acid and the solution dialysed against distilled water overnight. The dialysate was then centrifuged to remove a small amount of insoluble material, evaporated under reduced pressure to small volume and freeze-dried to give poly(sodium 3-O-methacryloyl-D-gluconate) as a white solid (78.0 mg., 73.0%). $[\alpha]_D^{19}$ + 3° in water (c, 0.451). $[\eta]$ 0.47 in water.

Found: Na, 7.97. $(C_{10}H_{15}O_8Na)_n$ requires Na, 8.03%.

An/...

A 0.5% (w/v) aqueous solution (3 ml.) of the sodium salt of the polymer acid was mixed with an equal volume of a 1% (w/v) aqueous solution of various salts and the results are recorded in Table 6, p. 90.

Acetylation of Poly(3-O-methacryloyl-D-glucose)

(a) With pyridine and acetic anhydride (Black and Dewar, 1954)

Deacetonated polymer (102.8 mg.), dissolved in water (10 ml.), was reprecipitated in ethanol (67 ml.) and the precipitate was washed with ether. While still wet, the finely divided solid was treated with pyridine (3 ml.) and acetic anhydride (1 ml.) at 20° for 48 hr. with occasional shaking and the suspension was then poured into water (40 ml.). The white solid was centrifuged, washed with water and dried to a white powder [41.8 mg., 24.3% yield calculated on the fully acetylated structure $(C_{18}H_{24}O_{11})_n$].

(b) With dimethylformamide, pyridine and acetic anhydride (Schlubach and Repenning, 1959).

Deacetonated polymer (50.6 mg.) dissolved in dimethylformamide (5 ml.), was treated with anhydrous pyridine (0.6 ml.) and acetic anhydride (1.2 ml.) at 20° for 24 hr. before precipitation in water (20 ml.) and working up as in (a) to a white solid (66.8 mg., 78.7% yield calculated on the fully acetylated structure $[(C_{18}H_{24}O_{11})_n]$.

Preparation of Poly(1,2,4,6-tetra-O-acetyl-3-O-methacryloyl-D-glucopyranose)

Poly(3-O-methacryloyl-D-glucose) (997 mg.) was shaken with dimethylformamide (50 ml.) until completely dissolved, when pyridine (6 ml.) and acetic/...

acetic anhydride (12 ml.) were added, the solution kept at 20° for 24 hr. and then poured into water (400 ml.). The precipitate was centrifuged, washed with water, dried and finally reprecipitated from solution in chloroform (15 ml.) with light petroleum (b.p. 40-60°; 150 ml.) as a white powder, poly(1,2,4,6-tetra-O-acetyl-3-O-methacryloyl-D-glucopyranose) (1.320 g., 79.0% yield calculated on the fully acetylated structure $[(C_{18}H_{24}O_{11})_n]$. $[\alpha]_D^{21}$ + 43° (c, 0.496). $[\eta]$ 0.38.

Found: C, 51.3; H, 6.20; CH_3CO, 39.5, 42.9. $(C_{18}H_{24}O_{11})_n$ requires C, 51.9; H, 5.81; CH_3CO, 41.4%.

Attempted Preparation of Poly(2,4,6-tri-O-acetyl-3-O-methacryloyl-D-glucopyranosyl bromide).

Acetylated polymer (102.5 mg.) was dissolved in glacial acetic acid (1 ml.) and cooled to 0° before glacial acetic acid containing 50% of hydrobromic acid (4 ml.) also at 0° and acetic anhydride (0.2 ml.) were added. The solution was kept at 20° for 3 hr., chloroform (6 ml.) added, and the solution poured into a mixture of ice and water (25 ml.) and extracted with chloroform (3 x 10 ml.); the formation of stable emulsions rendered the extractions difficult and led to appreciable loss of material. The chloroform extracts were washed with iced water and cold sodium bicarbonate solution, dried (sodium sulphate) and repeatedly evaporated under reduced pressure with acetone to a solid (41.9 mg., 38.9% yield).

Found: CH_3CO, 15.3; Br, 9.9. $(C_{16}H_{21}O_9Br)_n$ requires CH_3CO, 29.5; Br, 18.3%.

Methylation of Poly(3-O-methacryloyl-D-glucose)

Methylation was effected with Purdie's reagent in dimethylformamide solution (Kuhn et al., 1955). Deacetonated polymer (97.9 mg.) was dissolved in dimethylformamide (4 ml.), pure methyl iodide (1.5 ml.) and dry silver oxide (1.5 g.) added in portions and the mixture shaken at 20° for 17 hr. The residue was centrifuged and washed with dimethylformamide (5 ml.) and chloroform (5 ml.); the centrifugate and washings were treated with 1% potassium cyanide solution (50 ml.) and the mixture extracted with chloroform (5 x 10 ml.). The combined extracts were washed with water, dried (sodium sulphate) and concentrated under reduced pressure to a small volume (10 ml.), before being poured into light petroleum (b.p. 40-60°; 100 ml.). The precipitate was centrifuged, washed with light petroleum (b.p. 40-60°; 2 x 50 ml.) and dried to a white powder (95.9 mg.).

Found: OMe, 30.0. The tetra-O-methyl derivative $(C_{14}H_{24}O_7)_n$ requires OMe, 40.8%.

The partially methylated polymer (81.8 mg.), dissolved in methyl iodide (5 ml.), was treated at 45° with portions (1 g.) of silver oxide at 1 hr. intervals for 6 hr. The residue was filtered, washed with boiling chloroform (3 x 5 ml.) and the filtrate and washings concentrated under reduced pressure to small volume (10 ml.) before being poured into light petroleum (b.p. 40-60°; 100 ml.). The precipitate was centrifuged, washed with light petroleum (b.p./...

(b.p. 40-60°) and dried, after which the product was methylated in the same way again and finally isolated as a white powder (63.7 mg.). $[\alpha]_D^{19}$ +15° (c, 1.08).

Found: OMe, 36.0. The tetramethyl derivative $(C_{14}H_{24}O_7)_n$ requires OMe, 40.8%.

Preparation of Poly(3-O-methacryloyl-tri-O-phenylcarbamoyl-D-glucose)

The method of Bouveng (1961) was used. Deacetonated polymer (202.1 mg.) was dissolved in dimethylformamide (10 ml.), phenylisocyanate (1 ml.) added and the solution heated at 100° for 3 hr. before it was poured into ethanol (100 ml.). The precipitate was washed with ethanol and ether and dried; the treatment was then repeated to give a pale brown powder (397 mg.) which was purified by solution in acetone and reprecipitation in light petroleum (b.p. 40-60°; 100 ml.). The precipitate was washed with light petroleum (b.p. 40-60°) and dried to a white powder (379 mg., 76.8%) which analysed as poly(3-O-methacryloyl-tri-O-phenylcarbamoyl-D-glucose). $[\alpha]_D^{20}$ +25.5° (c, 0.51). $[\eta]$ 0.32.

Found: C, 60.9; H, 5.10; N, 6.9. $(C_{31}H_{31}N_3O_{10})_n$ requires C, 61.5; H, 5.16; N, 6.9%.

Preparation of Poly(methyl 3-O-methacryloyl-D-glucopyranoside)

Deacetonated polymer (99.4 mg.) was refluxed for 3 hr. with methanol (10 ml.) containing 1.5% hydrogen chloride, when the bulk of the polymer failed to dissolve. The residue was centrifuged, washed with methanol (3 x 5 ml.) and/...

and dried to a white powder (67.0 mg., 63.8% yield as the methyl glycoside).

Found: OMe, 9.7. $(C_{11}H_{18}O_7)_n$ requires OMe, 11.8%.

Preparation of Poly(3-O-methacryloyl-D-glucosephenylhydrazone)

The phenylhydrazone was prepared by a method similar to that of Barry and Mitchell (1954). Deacetonated polymer (97.0 mg.), dissolved in 10% (v/v) acetic acid (10 ml.), was treated with freshly distilled phenylhydrazine (1 ml.). The yellow-orange precipitate, which separated immediately, was centrifuged, washed with 10% acetic acid and ethanol and dried to a yellow powder (98.9 mg., 74.8%).

Found: N, 7.6. $(C_{16}H_{22}N_2O_6)_n$ requires N, 8.3%.

Preparation of Poly(3-O-methacryloyl-D-glucose diphenylformazan)

A solution of phenyldiazonium chloride was prepared by the method of Mester and Major (1955). Freshly distilled aniline (2.5 g.) was dissolved in 18% (w/v) hydrochloric acid (12.5 ml.), the solution cooled to 0-5°, sodium nitrite (2.0 g.) dissolved in water (4 ml.) added dropwise with stirring and the solution diluted to 25 ml. A portion (1 ml.) of the diazotised aniline reagent was then added dropwise with stirring to the phenylhydrazone (95.7 mg.) in pyridine-ethanol (1:1 by volume; 10 ml.), cooled below -5°. After 10 min., the bright red precipitate was poured into ice-water and, after standing overnight, the poly(3-O-methacryloyl-D-glucose diphenylformazan) was centrifuged, washed with water and dried to a red powder (122.8 mg., 98.1%).

Found: N, 8.4. $(C_{22}H_{26}N_4O_6)_n$ requires N, 12.7%.

Attempted/...

Attempted Preparation of Poly(3-O-methacryloyl-D-glucose diethyl dithioacetal).

The method of Wolfrom and Karabinos (1945) was used. Deacetonated polymer (100.4 mg.) was dissolved in 11 N hydrochloric acid (5 ml.) at 0° and ethanethiol (0.5 ml.) added. After shaking for 1 hr. at 0°, the mixture was neutralised in the cold with concentrated ammonia solution (3 ml.). The white precipitate which resulted was treated with water (10 ml.), centrifuged, washed with ethanol (10 ml.) and dried to a white powder (29.4 mg.). Found: S, 9.3%. Washing with ethanol had caused some solution of the product which was recovered by precipitation in water (100 ml.), washing with water and drying to give another portion of white powder (21.8 mg.).

Found: S, 9.3. The diethyl dithioacetal $(C_{14}H_{26}O_6S_2)_n$ requires S, 18.1%.

II. 3-O-Allyl-1,2:5,6-di-O-isopropylidene-α-D-glucofuranose

Materials

Allyl chloride. British Drug Houses laboratory reagent, redistilled.

Allyl bromide. British Drug Houses laboratory reagent.

Dioxan. British Drug Houses laboratory reagent, dried over sodium hydroxide and sodium wire, refluxed and distilled over sodium wire.

General methods

Allyl content was determined by Wij's method as modified by Nichols and Yanovsky (1945). A portion (ca. 100 mg.) of the substance under test, dissolved in "Analar" glacial acetic acid (25 ml.), was treated with 0.2 N Wij's solution (25 ml.) in the dark for 4 hr. 15% Potassium iodide solution (25 ml.) and water (50 ml.) were then added and the liberated iodine titrated with 0.1 N sodium thiosulphate solution. A blank with 0.2 N Wij's solution (25 ml.) and glacial acetic acid (25 ml.) was run similarly. The allyl content was calculated from the difference in titres on the basis that 1 mmol. of an allyl compound ≡ 20 ml. 0.1 N sodium thiosulphate solution.

0.2 N Wij's solution was prepared by dissolving iodine (13.0 g.) in glacial acetic acid ("Analar"; 1 l.) at 80-90°, cooling the solution, removing 100 ml. and passing pure, dry chlorine gas through the remainder of the solution until the brown colour changed to orange, when the chlorine was quickly stopped. The 100 ml. portion was then added, the solution heated/...

heated at 80-90° for 20 min., cooled and stored in a brown bottle.

Paper partition chromatography was carried out on Whatman No. 1 paper (descending development):-

Solvent system A:- n-Butanol:ethanol:water - 40:11:19

B:- n-Butanol:ethanol:water - 4:1:5

Periodate oxidation was carried out by treating a 0.1% solution (10 ml.) of the derivative with 0.025 M sodium periodate (10 ml.) in a stoppered flask in the dark at 20°. Aliquot parts (2 ml.) were removed at selected intervals for estimation of periodate uptake (Jackson, 1944) and formic acid liberated (Halsall et al., 1947). Periodate consumption was determined by adding a measured excess of 0.1 N sodium arsenite solution (1 ml.), 10% potassium iodide solution (0.5 ml.) and sodium bicarbonate (1 g.), before back titration with 0.005 N iodine solution. Formic acid liberated during the reaction was estimated by direct titration with 0.002 N sodium hydroxide solution, using screened methyl red indicator, after excess periodate had been destroyed with ethylene glycol (0.5 ml.).

Other materials and general methods were as reported before (p. 18).

Reactions of Diisopropylideneglucose in Liquid Ammonia

(a) Preparation of 1,2:5,6-di-O-isopropylidene-3-O-methyl-α-D-glucofuranose

DIPG (1.009 g.; 3.88 mmol.) was dissolved in anhydrous liquid ammonia (50 ml.) at -33° in the apparatus designed for the preparation of sodium sucrates (Arni et al., 1959). Sodium (ca. 100 mg.; 4.35 mg.-atom) was added, followed after 15 min. by methyl iodide (0.25 ml.; 4.0 mmol.). The sodium-methyl iodide addition was repeated seven times until a total of 874 mg. sodium and 2.0 ml. methyl iodide had been added; methyl iodide (0.25 ml.) was added finally to dispel the blue colour of excess sodium present in the liquid ammonia solution. Ammonia was allowed to evaporate off, the residue extracted with dry ether (3 x 100 ml.) under reflux and the filtered extracts concentrated under reduced pressure to a light brown oil (0.966 g., 90.9% yield), which was purified by high vacuum distillation to give 1,2:5,6-di-O-isopropylidene-3-O-methyl-α-D-glucofuranose as a colourless oil (824 mg., 77.8% yield). B.p. 96-7°/0.35 mm. n_D^{24} 1.4490; $[\alpha]_D^{24}$ - 32.0° in ethanol (c, 2). Found: OMe, 11.1. Calc. for $C_{13}H_{22}O_6$: OMe, 11.3%.

Muskat (1934) prepared this derivative by one treatment with potassium and methyl iodide in liquid ammonia and isolated it in 96% yield. B.p. 105°/0.3 mm. $[\alpha]_D^{26}$ - 34.6° in ethanol (c, 2); n_D^{24} 1.451.

(b) Attempted preparation of 3-O-allyl-1,2:5,6-di-O-isopropylidene-α-D-glucofuranose

DIPG (1.000 g.; 3.84 mmol.) in anhydrous liquid ammonia (50 ml.) at -33°/...

-33° was treated eight times with sodium (ca. 100 mg.; 4.35 mg.-atom) and allyl chloride (0.35 ml.; 4.3 mmol.), with a final addition of allyl chloride (0.35 ml.) to dispel the blue colour. After removal of ammonia, the solid residue was extracted with ether (3 x 100 ml.) and the filtered extracts after concentration under reduced pressure crystallised as needles (1.053 g.; m.p. 106°) of DIPG. A strong smell of allylamine was detected.

(c) Preparation of 1,2:5,6-di-O-isopropylidene-3-sodio-α-D-glucofuranose

DIPG (2.999 g.; 11.53 mmol.) in anhydrous liquid ammonia (100 ml.) at -33° was treated with sodium (0.269 g.; 11.69 mg.-atom) and the solution stirred to clear the blue colour. The salt was completely soluble and was obtained as a glass on evaporation of the ammonia under anhydrous conditions. Found: Na, 8.1; N, 0.19. Calc. for $C_{12}H_{19}NaO_6$: Na, 8.15; N, 0.0%.

Preparation of 3-O-Allyl-1,2:5,6-di-O-isopropylidene-α-D-glucofuranose

(a) From the 3-sodio salt of DIPG and allyl chloride

The 3-sodio salt (8.817 g.) was heated with excess allyl chloride (30 ml.) in a sealed tube at 122° for 3 hr. After the separation of precipitated sodium chloride (quantitative recovery), the allyl chloride filtrate was concentrated under reduced pressure to a brown syrup (9.346 g.), which did not deposit any DIPG on dissolution in light petroleum (b.p. 60-80°; 90 ml.). The light petroleum solution was then concentrated under reduced pressure to a syrup which on distillation under high vacuum gave 3-O-allyl-1,2:5,6-di-/...

di-O-isopropylidene-α-D-glucofuranose as a colourless oil (6.871 g., 73.3% yield). B.p. 90-8°/0.03-0.05 mm.; n_D^{23} 1.4571; $[\alpha]_D^{23}$ -23.0° in ethanol (c, 1.961).

Found: $CH_2CH=CH_2$, 14.4. Calc. for $C_{15}H_{24}O_6$: $CH_2CH=CH_2$, 13.7%.

(b) From DIPG, allyl bromide and sodium hydroxide (Corbett and McKay, 1961)

DIPG (20 g.), powdered sodium hydroxide (8 g.) and dioxan (100 ml.) were heated together at 45° with stirring while allyl bromide (80 ml.) was added dropwise over a period of 20 min. The yellow suspension was then stirred at 50° for 1.5 hr. and finally at 60° for 2 hr. Water (100 ml.) was added and the mixture extracted with chloroform (3 x 100 ml.). The extract was washed with water, dried (sodium sulphate) and concentrated under reduced pressure to an oily liquid which after distillation under high vacuum yielded the 3-O-allyl ether as a colourless oil (21.60 g., 93.7%). B.p. 88°/0.08 mm.; n_D^{20} 1.4578; $[\alpha]_D^{19}$ -27.1° in ethanol (c, 2.507), -28.8° in chloroform (c, 2.539).

For polymerisation studies the ether was redistilled under high vacuum. Yield, 21.11 g. B.p. 75°/0.08 mm. n_D^{20} 1.4578.

Found: C, 59.3; H, 7.8. Calc. for $C_{15}H_{24}O_6$: C, 60.0; H, 8.1%.

The compound showed no OH absorption around 3400 cm^{-1} in the infrared but had ν_{max} (cm^{-1}): 2980 (C-H), 1365, 1250, 1215, 1165, 1080, 1020, 940, 890, 850. (Film between sodium chloride plates; Appendix II).

A/...

A small (C=C) absorption peak occurred at 1645 cm^{-1} (Davison and Bates, 1953).

Corbett and McKay (1961) briefly reported this preparation without recording the yield. B.p. 113° (bath temperature)/0.005 mm. n_D^{24} 1.4570. $[\alpha]_D^{20}$ - 12.7° (c, 2.4 in chloroform).

Preparation of 3-O-Allyl-D-glucose

The first 3-O-allyl ether (196 mg.) from (a) before was deacetonated by heating with 0.5 N sulphuric acid (10 ml.) at 100° for 2 hr. The solution was neutralised with 15% (w/v) sodium hydroxide solution, sodium sulphate precipitated with ethanol (150 ml.), centrifuged, and the centrifugate concentrated under reduced pressure. The syrupy residue was extracted with ethanol (3 x 10 ml.), decolourised with charcoal, and the solution after evaporation afforded syrupy 3-O-allyl-D-glucose (148 mg., 103%). $[\alpha]_D^{23}$ +24° in water (c, 0.463). Chromatography of the syrup in solvent system A with benzidine-trichloroacetic acid spray showed a small amount of contaminating glucose (R_f 0.20) in addition to 3-O-allyl-D-glucose (R_f 0.56); 3-O-methyl-D-glucose had R_f 0.32.

A sample of the second 3-O-allyl ether (206 mg.) prepared by method (b) was then similarly deacetonated with 0.5 N sulphuric acid (10 ml.) at 100° for 1.25 hr. 3-O-allyl-D-glucose was obtained as a clear syrup (147 mg., 97%) which slowly crystallised. Chromatography of the product in solvent/...

solvent system B with benzidine-trichloroacetic acid spray showed only one component, 3-O-allyl-D-glucose (R_f 0.63); D-glucose had R_f 0.22.

Periodate Oxidation of Methyl 3-O-Allyl-D-glucopyranoside

Glucopyranoside formation was effected by heating 3-O-allyl-D-glucose (37.9 mg.) with 1.5% methanolic hydrogen chloride (10 ml.) under reflux for 4 hr., when the rotation was constant (α_D +0.38°; 1 dm.), neutralising with silver carbonate, filtering, treating the filtrate with charcoal, and concentrating the filtered solution under reduced pressure to a syrup (38.8 mg.).

The syrupy methyl 3-O-allyl-D-glucopyranoside (10.4 mg.), dissolved in water (10 ml.), was treated with 0.025 M sodium periodate solution (10 ml.) in a stoppered flask in the dark at 20°; at intervals aliquots were removed for estimation of periodate uptake and formic acid liberated. Authentic methyl 3-O-methyl-D-glucopyranoside was treated similarly in a parallel experiment. Results are summarised in Table 7, p. 100.

Attempted Polymerisation of 3-O-Allyl-1,2:5,6-di-O-isopropylidene-α-D-glucofuranose

Purified monomer (p. 45, b) (1 g.) with benzoyl peroxide (10 mg.) was heated at 80° ±0.1 for 24 hr. in a sealed tube which had been degassed four times and flushed with nitrogen twice. When cooled, the reactants were observed to have the same viscosity as the pure monomer. The contents of the tube were diluted with benzene (2 ml.) and poured into stirred methanol (100 ml.), but no precipitate was formed. When increased quantities (50 mg., 100 mg.)/...

100 mg.) of benzoyl peroxide were used in parallel experiments, the reactants were noticeably less mobile on cooling; however, no polymer was isolated by precipitation in methanol.

Three similar experiments were conducted with monomer (1 g.) diluted with benzene (1 ml.) using benzoyl peroxide (10 mg., 50 mg., 100 mg.) at 80° $\pm$0.1 for 24 hr. No polymer precipitated on pouring into methanol.

III. 1,2:5,6-Di-O-isopropylidene-3-O-vinyl-α-D-glucofuranose

Materials

Vinyl chloride. Imperial Chemical Industries reagent was purified by passing through columns of barium oxide and calcium chloride before being condensed in acetone-solid carbon dioxide cooling mixture under anhydrous conditions.

Vinyl bromide. British Drug Houses laboratory reagent, stabilised with 1% ethanol.

1,2:5,6-Di-O-isopropylidene-3-potassio-α-D-glucofuranose. Prepared similarly to the 3-sodio salt (p. 44) by treating DIPG in liquid ammonia with potassium, and isolated as a pale yellow glass.

Found: K, 12.7; N, 0.04. $C_{12}H_{19}KO_6$ requires K, 13.1; N, 0.0%.

Isobutyl vinyl ether. Eastman Organic Chemicals reagent was dried over sodium sulphate and fractionally distilled, b.p. 83-4°.

Mercuric acetate. Commercial samples could not be obtained free from acetic acid contamination as recommended by Inglis et al. (1962) for methoxymercuration. British Drug Houses reagent was recrystallised from water and washed with ice-cold water until free from acetic acid.

Ultrasonically dispersed sodium. Kindly supplied by Dr. M.W.T. Pratt, Imperial Chemical Industries Ltd.; 20% (w/w) in petroleum jelly.

Sodium wire. Formed immediately before use by extrusion from sodium pellets (British Drug Houses reagent; each pellet ca. 2.5 g.), after/...

after washing with light petroleum (b.p. 60-80°).

Propane. British Oxygen Company commercial grade; attempted purification described below (p. 60).

Boron trifluoride etherate (BTFE). British Drug Houses reagent redistilled before use, b.p. 125-6°, (1 drop ≡ ca. 10 mg.).

Methylene dichloride. British Drug Houses laboratory reagent was dried by storing over calcium chloride for several months and redistilled before use, b.p. 39.5 - 40.5°. The presence of traces of water in this reagent was noted by the opacity or slight precipitate formed when the solvent was cooled to low temperature (<-60°).

Hexane. British Drug Houses spectroscopic grade reagent.

Stannic chloride. British Drug Houses reagent, filtered before use.

Silver perchlorate. British Drug Houses reagent, dried at 120° for 72 hr.

General Methods

Paper partition chromatography was carried out on Whatman No. 1 paper (descending development) with the following systems:-

Solvent system A:- n-Butanol:ethanol:water - 40:11:19

D:- n-Butanol:acetic acid:water - 12:3:5

Chromatographic separation of DIPG derivatives was carried out on cellulose acetate strips by ascending development with solvent system C (methanol:water/...

(methanol:water - 6:4) at 2° for 2 hr. (Barnett and Kent, 1961). After drying, the chromatograms were floated on the surface of a solution (1% w/v) of potassium permanganate in N sulphuric acid for 2 min. and immersed for a further 1 min., before being washed in water when sharply-defined, purple-brown spots appeared.

Other materials and general methods were as reported before (pp. 18, 41).

Attempted Preparations of 1,2:5,6-Di-O-isopropylidene-3-O-vinyl-α-D-gluco-furanose using Vinyl Halides.

A series of reactions was carried out in which the 3-sodio salt of DIPG (see p. 44) (ca. 500 mg.) was heated with vinyl chloride (10 ml.) in a stainless steel bomb for 2 hr. at different temperatures. After the bonb had been cooled, excess vinyl chloride was allowed to evaporate off under anhydrous conditions at room temperature, and the residue was extracted, first with cold light petroleum (b.p. 60-80°; 3 x 10 ml.) to extract vinyl ether and then with hot ether (3 x 10 ml.) to extract DIPG. The brown residue was then exhaustively extracted with water and the aqueous extracts neutralised with nitric acid before titration with 0.1 N silver nitrate solution. Percentage reaction was calculated from the sodium chloride content; the results are recorded on p. 106.

In the final experiment (140°) the light petroleum extracts were concentrated under reduced pressure to a syrup (65 mg.), while the ether extracts, similarly treated, formed a yellow solid (509 mg.) which on recrystallisation from light petroleum (b.p. 60-80°) yielded DIPG, m.p. and mixed m.p. 109-110°. Further experiments for a 2 hr. reaction period were carried out in a similar manner with the 3-sodio salt and vinyl chloride, and with the 3-potassio salt and either vinyl chloride or vinyl bromide; the results are summarised in Table 8, p. 107.

Three further experiments (Table 9, p.108) were carried out under conditions/...

conditions similar to those employed by Mikhant'ev and Lapenko (1957), using DIPG instead of its salts and vinyl chloride and powdered potassium hydroxide to produce acetylene in situ. Where dioxan was introduced as solvent, the reaction mixture was filtered and the filtrate concentrated under reduced pressure to a dark red syrup which was then extracted as before with light petroleum (b.p. 60-80°) and ether. DIPG was not recovered from the ether extract in these experiments. Percentage reaction was again calculated from the potassium chloride content of the residue.

Preliminary Preparations of 1,2:5,6-Di-O-isopropylidene-3-O-vinyl-α-D-glucofuranose by a Transvinylation Reaction.

The general method of preparation was that of Watanabe and Conlon (1957). DIPG (25 g.), isobutyl vinyl ether (250 ml.) and mercuric acetate (6.25 g.) were refluxed together for 6 hr. after which the solution was rapidly cooled. (Where different quantities of DIPG were used, the other reactants were introduced in equivalent quantities.) The solution was then worked up in a manner designed to isolate the monomer in optimum yield and purity. The development of this procedure is outlined below:-

(1) With the addition of potassium carbonate to inactivate the catalyst.

On the 10 g. DIPG scale, anhydrous potassium carbonate (5 g.) was added to the cooled solution from which unreacted DIPG then crystallised out and was removed by filtration. The filtrate and light petroleum (b.p. 60-80°) washings were concentrated under reduced pressure to 40-50 ml.; more DIPG then/...

then crystallised out on standing and was filtered. The filtrate and washings were again concentrated to a syrup but attempts to isolate the vinyl ether from this syrup by high vacuum distillation in the presence of barium carbonate were unsuccessful. Above 120° (bath temperature), decomposition occurred, both mercury and DIPG being found among the decomposition products.

(2) Without addition of potassium carbonate

The cooled reaction solution was kept at 0°, the DIPG which crystallised out was filtered and washed with light petroleum, and the filtrate and washings washed with 5% sodium hydroxide solution (3 x 75 ml.) and dried (sodium sulphate). Concentration and high vacuum distillation of the resulting syrup yielded the vinyl ether [0.560 g., 5.1%, based on the original weight of DIPG (10 g.)] as a colourless syrup which partially crystallised on standing. B.p. 82°/0.06 mm. n_D^{20} 1.4610. $[\alpha]_D^{20}$ -26° in ethanol (c, 0.51).

Infrared analysis revealed a small absorption peak at 3480 $cm.^{-1}$ (CH) and a strong doublet at 1645, 1620 $cm.^{-1}$ (C=C). $\nu_{max.}$ ($cm.^{-1}$): 3020, 1645, 1620, 1380, 1260, 1220, 1200, 1170, 1085, 1030, 890, 850.

Mikhant'ev and Lapenko (1957) reported b.p. 115-6°/1.5 mm. and n_D^{20} 1.468 for their DIPG vinyl ether.

Chromatography of the product in solvent system C with potassium permanganate detector revealed a major component (R_f 0.28), a minor component (R_f 0.37) and a small amount of contaminating DIPG (R_f 0.60).

When/...

When the experiment was repeated with 20 g. DIPG, a yield of 0.935 g. (4.3%) was obtained. On the 50 g. scale, high vacuum distillation was carried out twice and the final product was a colourless syrup (4.032 g., 7.3%; product A) which slowly crystallised. B.p. 80°/0.02 mm. n_D^{20} 1.4600. $[\alpha]_D^{20}$ -27° in ethanol (c, 0.50). Infrared and chromatographic analyses (solvent system C) were similar to those recorded previously.

The semi-crystalline product (4 g.) was dissolved in hot hexane (10 ml.) and the solution kept at 0° overnight to promote crystallisation. The isolated crystals, however, proved to be DIPG, m.p. 108-9° and mixed m.p. 109°. The mother liquor was concentrated under reduced pressure to a syrup which was redistilled to give a colourless oil (2.024 g.; product B), which showed no tendency to crystallise on standing. B.p. 76°/0.01 mm. n_D^{19} 1.4592. The infrared spectrum showed a reduction in the absorption peak at 3480 $cm.^{-1}$

Although procedure (2) proved satisfactory initially, yields were poor and somewhat variable. Difficulty was experienced at the first high vacuum distillation stage in all preparations; some decomposition always occurred, with the formation of a yellow gum containing free and combined mercury and with the formation of DIPG at higher temperatures (>150°, bath temperature). At this stage monomer was purified by distillation over a piece of sodium or potassium (b.p.67°/0.01 mm) affording a clear, colourless distillate showing no OH absorption in the infrared.

Found: C, 58.6; H, 7.5. Calc. for $C_{14}H_{22}O_6$, C, 58.7; H, 7.75%.

(3)/...

(3) Removal of organomercury compounds

(a) With potassium carbonate and ammonia.

An attempt was made to inactivate the catalyst after the reaction by adding potassium carbonate (5 g.). The solution was then washed with concentrated ammonia solution (S.G. 0.880; 2 x 100 ml.), dried (sodium sulphate) and evaporated under pressure. The presence of mercury compounds and DIPG was again noted during the final distillation.

(b) With ultrasonically dispersed sodium.

In a further 10 g. scale experiment the cooled reactants were washed with 5% sodium hydroxide solution (3 x 50 ml.) and dried (sodium sulphate). After concentration under reduced pressure to remove unreacted isobutyl vinyl ether, light petroleum (b.p. 60-80°; 50 ml.) was added and crystalline DIPG removed. Ultrasonically dispersed sodium (5 g.) (Pratt and Helsby, 1959) in light petroleum (b.p. 60-80°; 50 ml.) was added to the filtrate and the mixture stirred for 30 min. under nitrogen at 20°. The sodium amalgam was centrifuged, the centrifugate concentrated under reduced pressure and the syrupy product distilled, affording the vinyl ether (1.150 g., 10.5%). B.p. 84°/0.05 mm. n_D^{20} 1.4595. The product showed only a small absorption (OH) peak at 3490 $cm.^{-1}$

On the 25 g. scale, the vinyl ether was obtained in 15.1% yield (4.156 g.). DIPG was recovered from the sodium hydroxide washings (3 x 200 ml.) by extraction with chloroform (3 x 150 ml.); the extracts were washed/...

washed with water, dried (sodium sulphate) and concentrated at 30° to a crystalline mass of DIPG (17.4 g., 69.6%). M.p. and mixed m.p. 108-109°. On the basis of recovered DIPG, the yield of vinyl ether was 49.7%.

(c) With sodium wire

In a similar experiment (10 g. DIPG), sodium wire (ca. 2.5 g.) was added instead of the sodium dispersion in (b) above, the mixture was left for 17 hr. at 20° and the residue of sodium amalgam and brown solids centrifuged. The centrifugate and light petroleum washings were concentrated under reduced pressure and the syrup distilled from sodium wire, yielding a product (1.68 g., 15.3%) identical with the previous sample by infrared analysis. n_D^{20} 1.4590. In another preparation, treatment with sodium wire for 3 hr. at 20° proved insufficient.

On the 25 g. scale, the light petroleum solution was heated (70-80°) in the presence of sodium wire (ca. 5 g.) for 45 min. to complete the reaction. Yield of the vinyl ether was 6.084 g. (22.1%), although the product contained some DIPG. Recovered DIPG was 17.7 g. (70.8%) and the overall yield of vinyl ether was 75.8%.

(4) Final purification of the monomer

The products from preparations 3(b) and 3(c) were bulked (14.6 g.), dissolved in light petroleum (b.p. 60-80°; 100 ml.), the solution washed with 5% sodium hydroxide solution (3 x 50 ml.) to remove traces of DIPG, dried (sodium sulphate) and treated with sodium wire (ca. 2.5 g.) overnight at/...

at 20°. The solution was decanted and evaporated under reduced pressure to a yellow syrup which was distilled (70°/0.008 mm.) over sodium to yield a syrup (10.56 g.). Redistillation (86°/0.01 mm.) was then carried out over potassium but the clear distillate (9.005 g.) obtained had an acetylenic smell; infrared analysis showed new absorption peaks at 2390 and 2340 $cm.^{-1}$

A further batch of crude monomer was then subjected to triple distillation over sodium wire (b.p. 68°/0.008 mm.) after removal of excess DIPG by filtration of its light petroleum solution (b.p. 60-80°; 25 ml.). The product (C) (4.976 g.) was found to be pure on infrared examination.

The next sample of impure vinyl ether (7.938 g., 14.4%) did not deposit DIPG on standing; triple distillation (b.p. 68°/0.008 mm.) over sodium wire afforded pure monomer (6.570 g.; product D). Similarly, on the 50 g. scale, crude monomer (7.018 g.; 12.8%) yielded a pure product (5.791 g.), n_D^{21} 1.4591, after triple distillation from sodium wire.

(5) Improved working-up procedure

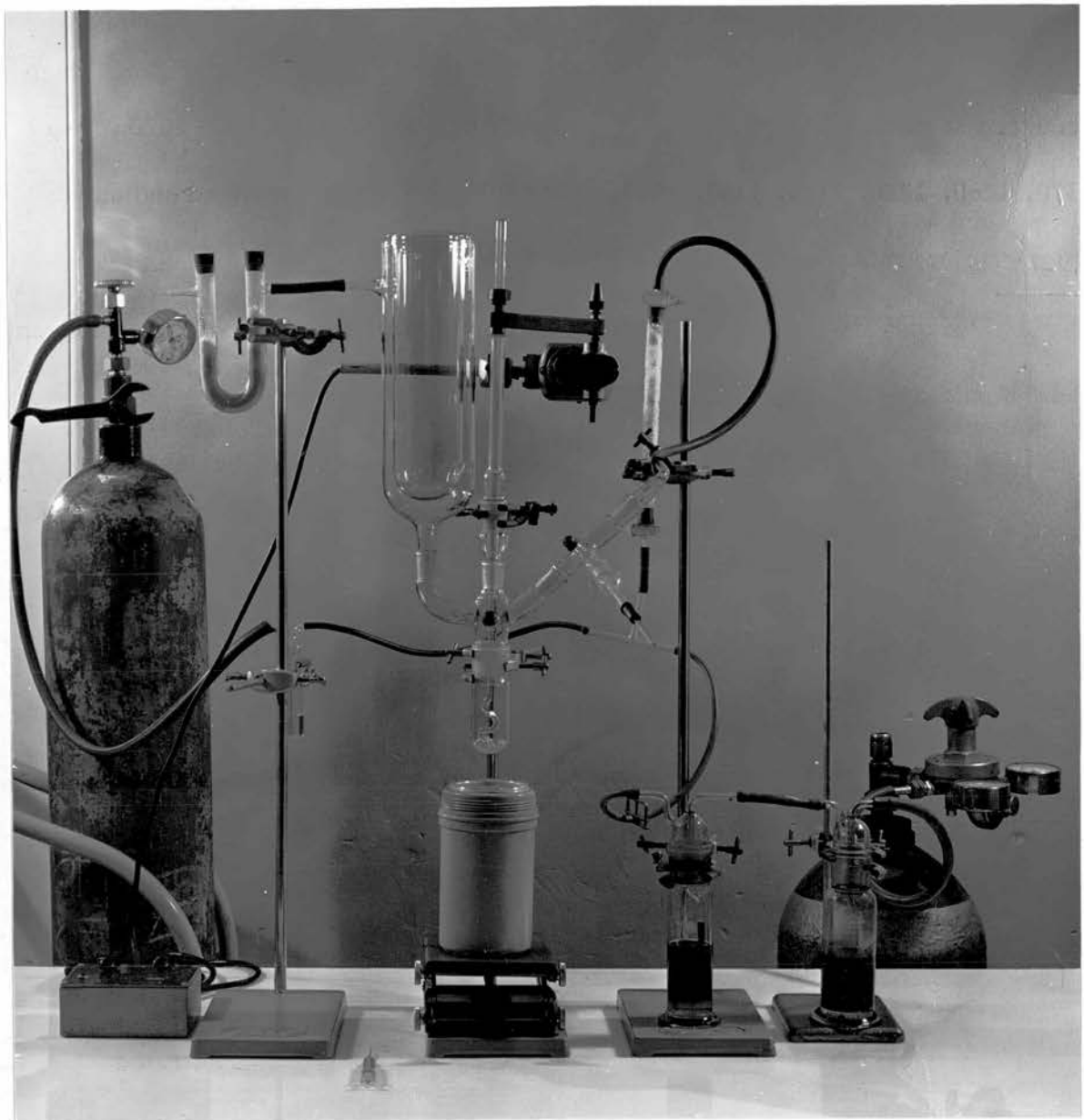
After the initial reaction (50 g., DIPG), and washing with 5% sodium hydroxide solution (3 x 200 ml.) and drying (calcium sulphate), the isobutyl vinyl ether solution was treated with sodium wire (ca. 10 g.) overnight at 20°. The supernatant and washings (light petroleum, b.p. 60-80°; 100 ml.) were again washed with 5% sodium hydroxide (3 x 200 ml.), dried (calcium sulphate), and evaporated under reduced pressure to a syrup which was distilled for collection of crude monomer (10.03 g., 18.2%). DIPG (32.4 g., 64.8%)/...

64.8%) was recovered from the first sodium hydroxide washings by extraction with chloroform (3 x 200 ml.). Overall yield of vinyl ether = 51.8%. Triple distillation over sodium wire afforded pure vinyl ether (7.733 g.), n_D^{21} 1.4592; infrared analysis showed complete absence of OH absorption.

Standard Preparation of 1,2:5,6-Di-O-isopropylidene-3-O-vinyl-α-D-gluco-furanose.

DIPG (25 g.), isobutyl vinyl ether (250 ml.) and pure mercuric acetate (6.25 g.) were refluxed for 6 hr., and the solution rapidly cooled, washed with 5% sodium hydroxide solution (3 x 100 ml.) and dried (calcium sulphate), before treatment with sodium wire (ca. 7.5 g.) at 20° overnight. The brown supernatant was carefully decanted from the solid residue containing sodium amalgam, and, together with washings (light petroleum, b.p. 60-80°; 50 ml.), was washed with 5% sodium hydroxide solution (3 x 100 ml.), which caused most of the colour to disappear. The crude product (7.676 g., 27.9%), obtained by evaporation of the solution under reduced pressure and high vacuum distillation, was purified by triple distillation over sodium wire. The product, pure 1,2:5,6-di-O-isopropylidene-3-O-vinyl-α-D-glucofuranose, was obtained as a colourless oil (5.938 g., 21.6%). B.p. 68°/0.008 mm. n_D^{20} 1.4593. $[\alpha]_D$ -23.8° in ethanol, -30.5° in chloroform, -22.8° in tetrachloroethane (c, 1) Found: C, 58.6; H, 7.50. Calc. for $C_{14}H_{22}O_6$: C, 58.7; H, 7.75%.

The derivative showed no OH absorption between 3400-3500 $cm.^{-1}$ but a strong doublet (C=C), characteristic of vinyl ethers (Davison and Bates, 1953) occurred/...



Apparatus for cationic, low-temperature polymerisations in liquid propane.

occurred at 1645, 1620 $cm.^{-1}$. $\nu_{max.}$ ($cm.^{-1}$): 3000 (C-H), 1645, 1620, 1370, 1260, 1220, 1195, 1165, 1085, 1025, 890, 850 (Film between sodium chloride plates; Appendix III).

Chromatography in solvent system C (detection with potassium permanganate) showed only one component (R_f 0.30).

Mikhant'ev and Lapenko reported this derivative as a colourless oil. B.p. 115-6°/1.5 mm. n_D^{20} 1.468.

Low-temperature Cationic Polymerisation of Isobutyl Vinyl Ether in Liquid Propane. (Sorenson and Campbell, 1961).

The apparatus designed for this reaction is shown opposite. It consists of a three-necked, elongated flask (50 ml. capacity) equipped with condenser (left), stirrer (centre) and a side-arm (right) containing a gas inlet and an almost horizontal side-arm, with a sleeved glass rod, for the introduction of pieces of solid carbon dioxide. Propane from the cylinder (lower right) was passed through two gas washers containing concentrated sulphuric acid and, together with oxygen-free nitrogen (cylinder on left), through a column of sodium hydroxide pellets. It was condensed using solid carbon dioxide in acetone and finally cooled to ca. -78° in the reaction vessel with the same cooling mixture. Liquid catalysts were introduced by injection from a hypodermic syringe through gas-tight "Subaseal" caps.

(a) Initial procedure

In the first experiment the side-arm (right) contained two gas inlets only/...

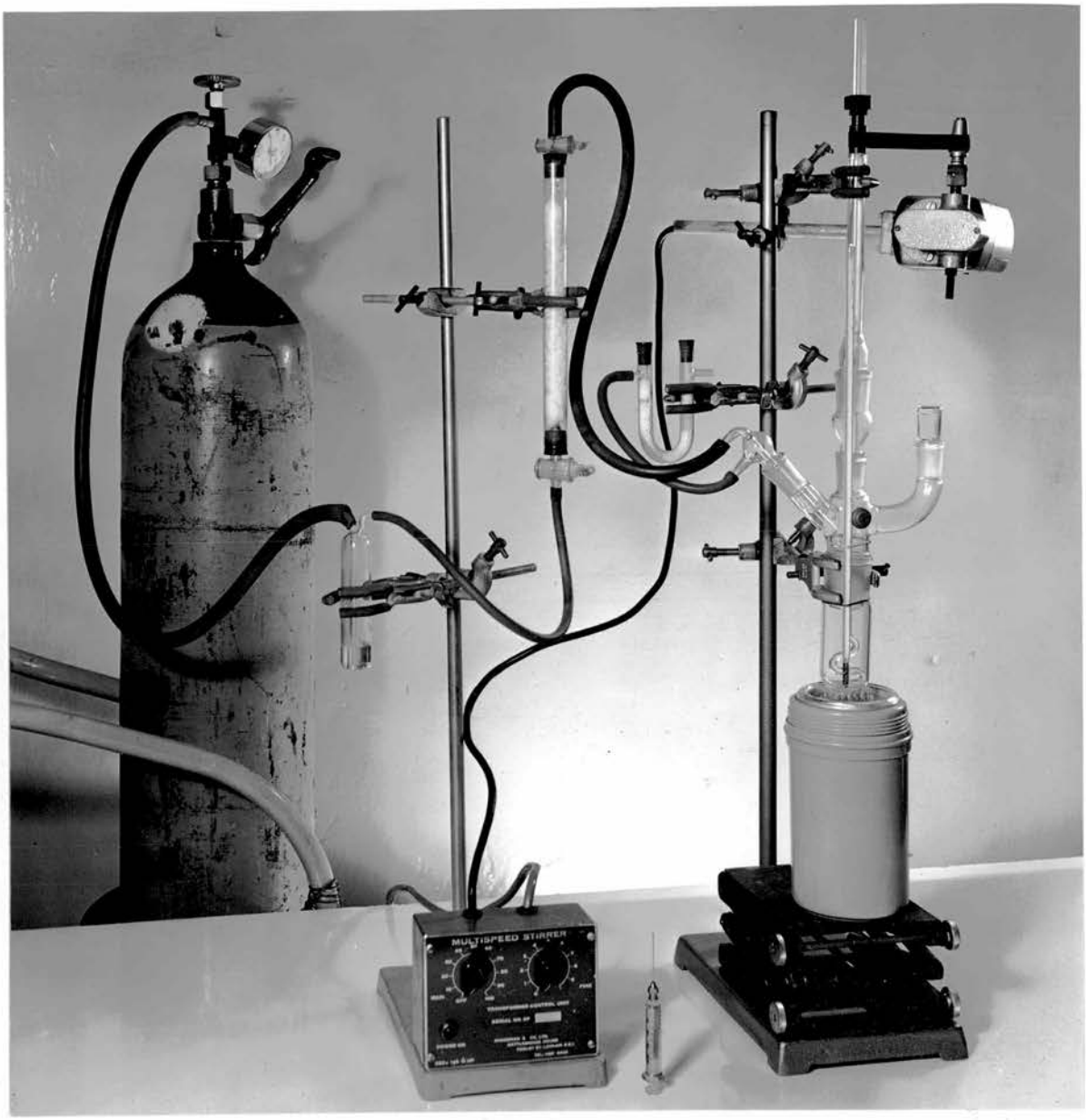
only, one for passing in dry, oxygen-free nitrogen throughout the reaction and the other for propane, which was dried by condensing it over sodium hydroxide pellets and a portion (20 ml.) condensed into the reaction vessel which contained isobutyl vinyl ether (5 ml., 3.85 g.). The stirred liquid propane-isobutyl vinyl ether solution was cooled to -78° and boron trifluoride etherate catalyst (30 mg.) added. A further addition (30 mg.) was made after 30 mins. and the reaction was allowed to proceed for 90 min. When cooling was discontinued, the propane evaporated off as the system approached room temperature. The dark brown residue was dissolved in hot benzene (30 ml.) and reprecipitated in methanol (300 ml.), forming a tough, yellow rubber (3.30 g., 85.7%). $[\eta]$ 0.48 in toluene (c, 0.2).

Sorenson and Campbell (1961) reported a 57-60% yield of white solid polymer with $[\eta]$ ca. 1.5 in toluene (c, 0.1).

(b) Improved procedure

Propane was passed through two gas washers containing concentrated sulphuric acid, causing heavy discolouration and tar formation, and over sodium hydroxide pellets, as shown. Boron trifluoride etherate catalyst was not added directly but was injected on to pieces of solid carbon dioxide contained in the horizontal side-arm, from where they were dropped into the reaction vessel.

Isobutyl vinyl ether (3.85 g.) was polymerised in liquid propane (20 ml.) with boron trifluoride etherate catalyst (2 x 10 mg., 20 min. between additions) to form a colourless gel. After 85 min., the propane was allowed to evaporate, the/...



Apparatus for cationic, low-temperature polymerisations.

the residue was dissolved in benzene (20 ml.), and the polymer precipitated in methanol (200 ml.). A pale yellow rubber was isolated (3.16 g., 75.9%). $[\eta]$ 1.66 in toluene (c, 0.1).

Investigation of the Effect of Dilution on the Polymerisation of Isobutyl Vinyl Ether

The addition of 1 drop of boron trifluoride etherate without solid carbon dioxide to 10% and 25% (v/v) solutions (2 ml.) of isobutyl vinyl ether in hexane at 20° caused charring around the insoluble drop of catalyst. At -60°, however, polymerisation occurred rapidly without charring on the addition of 1 drop of catalyst to the 25% solution but was considerably delayed in 10% solution. Equal volumes (0.5 ml.) of isobutyl vinyl ether and diethyl ether rapidly polymerised at 20° in the presence of 1 drop of catalyst, without charring.

Liquid propane was omitted from all further polymerisation experiments and, as a result, the apparatus previously described was considerably simplified. The modified form is shown opposite.

A 25% (v/v) solution (2 ml.) of isobutyl vinyl ether in hexane was polymerised at -60° for 1.5 hr. with boron trifluoride etherate (40 mg.) Rubbery polymer was isolated in 96.7% yield, $[\eta]$ 0.96 in toluene (c, 0.1). A 10% solution (2 ml.) was polymerised for 2.5 hr. and the product was obtained in 83.3% yield, $[\eta]$ 0.64 in toluene (c, 0.1). A 25% (w/v) solution (2 ml.) of the sugar vinyl ether (B, p. 55) in hexane solidified on cooling to -60°.

Preliminary/...

Preliminary Polymerisations of 1,2:5,6-Di-O-isopropylidene-3-O-vinyl-α-D-glucofuranose.

(a) In liquid propane

DIPG vinyl ether (A, p. 55; 702 mg.) was transferred to the reaction vessel with light petroleum (b.p. 60-80°; 10 ml.), the solvent removed under reduced pressure and liquid propane (10 ml.) distilled into the flask. The vinyl ether proved to be only sparingly soluble in liquid propane and dissolved with great difficulty. Polymerisation was carried out at -78° with boron trifluoride etherate (2 x 10 mg.; 20 min. between additions) in solid carbon dioxide; the residue after propane had been removed was dissolved in hot benzene (10 ml.) and reprecipitated in methanol (200 ml.) as a white powder (76 mg., 10.8%). P.M.T. 206-9°. $[\eta]$ 0.11. $[\alpha]_D^{20}$ +3° (c, 0.474). The polymer was insoluble in toluene.

(b) In methylene dichloride, hexane and liquid propane

Monomer (B, p. 55; 988 mg.), dissolved in a mixture of methylene dichloride (5 ml.), hexane (5 ml.) and liquid propane (10 ml.), was treated at -78° with boron trifluoride etherate in solid carbon dioxide as described in (a). No polymer precipitated on pouring the propane-free solution into methanol (200 ml.).

(c) In methylene dichloride and hexane.

Monomer (B, p. 55; 1.007 g.) was dissolved in methylene dichloride (2 ml.) and hexane (8 ml.), the solution cooled to -60° and treated with boron trifluoride/...

trifluoride etherate catalyst in solid carbon dioxide as in (a); no polymer precipitated on pouring into methanol (100 ml.).

(d) In methylene dichloride, using different polymerisation conditions and catalysts.

DIPG vinyl ether (B, p. 55; 250-500 mg.) in 1:1 (w/v) redistilled methylene dichloride solution was cooled and treated with catalyst added dropwise at 30 min. intervals. Thirty minutes after the last addition excess catalyst was destroyed with conc. ammonia solution (S.G. 0.880; 0.5 ml.) and polymer was precipitated with methanol (5-10 ml.), washed with methanol, and dried. The product obtained with stannic chloride catalyst was extracted with chloroform (2 x 5 ml.) (a small insoluble residue remained) and the chloroform extract reprecipitated in methanol (50 ml.). Aluminium chloride was introduced as a saturated solution in carbon tetrachloride and silver perchlorate as a saturated (ca. 2.0%) solution in ether.

Results are recorded in Table 10, p. 121.

For the first polymer (expt. 1), found: C, 58.25; H, 7.72. $(C_{14}H_{22}O_6)_n$ requires C, 58.7; H, 7.75%.

Comparison of Homogeneous and "Heterophase" Polymerisation of Isobutyl Vinyl Ether.

(a) Homogeneous polymerisation in methylene dichloride

Isobutyl vinyl ether (193 mg.) in methylene dichloride (1.0 ml.) was polymerised/...

polymerised with boron trifluoride etherate (50 mg.) at -78° over 2 hr.; a tacky syrup was obtained after trituration in methanol and drying (164 mg., 84.9%). $[\eta]$ 0.28 in toluene (c, 0.1).

(b) "Heterophase" polymerisation in hexane: methylene dichloride (3:1 v/v)

When isobutyl vinyl ether (193 mg.) in hexane:methylene dichloride (3:1, v/v; 1.0 ml.) at -78° was treated with boron trifluoride etherate (10 mg.), polymerisation occurred immediately around frozen particles of catalyst with the formation of a thick gel which, after trituration in methanol, was isolated as a white, non-tacky rubber (190 mg., 98.5%). $[\eta]$ 1.0 in toluene (c, 0.1).

Heterophase Polymerisation of 1,2:5,6-Di-O-isopropylidene-3-O-vinyl-α-D-glucofuranose

Monomer (B, p. 55; 250 mg.) in hexane:methylene dichloride (3:1, v/v; 1 ml.) was polymerised at -78° for 4 hr., catalyst being added dropwise at hourly intervals; polymer was isolated by methanol (10 ml.) precipitation in the presence of concentrated ammonia solution (0.5 ml.). With stannic chloride catalyst (added in 50% v/v methylene dichloride solution) the product was extracted with chloroform (2 x 5 ml.) and reprecipitated in methanol (50 ml.).

Results are recorded in Table 11, p. 124.

Large-scale Preparations of Poly(1,2:5,6-di-O-isopropylidene-3-O-vinyl-α-D-glucofuranose).

Highly purified 1,2:5,6-di-O-isopropylidene-3-O-vinyl-α-D-glucofuranose (C,/...

(C, p. 58; 4.976 g.) was dissolved in methylene dichloride (5 ml.)/hexane (15 ml.), the solution cooled to -78°, and boron trifluoride etherate catalyst (12 x 10 mg.) added, 2-3 drops at a time, over 80 min. After a further 20 min., polymerisation started and soon a large rubbery mass of insoluble polymer built up around the stirrer, leaving a clear homogeneous supernatant solution. Thirty minutes after the first sign of polymerisation, the reaction was arrested by the addition of concentrated ammonia solution (5 ml.) and methanol (50 ml.). Crude polymer (5.007 g.) was purified by solution in chloroform (50 ml.) containing pyridine (1 ml.) and gradual addition of the filtered solution to stirred methanol (500 ml.). The white, fibrous solid was washed with methanol (2 x 200 ml.) and dried to a white powder (3.853 g.; 77.4%. $[\eta]$ 0.65. $[\alpha]_D^{19}$ + 2° (c, 0.5). P.M.T. 199-201°.

Infrared analysis (Appendix III) showed the absence of the twin (C=C) peaks at 1645, 1620 $cm.^{-1}$ (Davison and Bates, 1953). $\nu_{max.}$ $(cm.^{-1})$: 3000 (C-H), 1380, 1220, 1170, 1150, 1080, 1025, 865 (potassium bromide disc).

Found: C, 58.7; H, 7.90. $(C_{14}H_{22}O_6)_n$ requires C, 58.7; H, 7.75%.

The polymer was soluble in cold chloroform and tetrachloroethane but insoluble in benzene, ether, dimethoxyethane, dioxan, acetone, ethyl acetate and water.

In a second large-scale experiment, pure monomer (D, p. 58; 6.570 g.) was polymerised as above with boron trifluoride etherate (11 x 10 mg.). After/...

After the reaction had been stopped by the addition of methanol and ammonia, the tough, rubbery polymer jammed the stirrer and could not be broken up, with the result that the product turned yellow on attaining room temperature, due to the presence of occluded catalyst. The crude polymer (5.83 g., 88.7%) was taken up in chloroform (100 ml.), benzene (100 ml.) was added, and an insoluble gel was separated by centrifugation. The filtered centrifugate was poured into methanol (2 l.) which precipitated a white powder (2.02 g., 30.7%). $[\eta]$ 0.41. $[\alpha]_D^{20}$ + 2° (c, 0.5).

In subsequent experiments on this scale the reaction was stopped by the addition of chloroform containing 10% (v/v) pyridine (50 ml.) and cooled to -60°, instead of by the ammonia-methanol treatment. The polymers readily dissolved on warming to room temperature and the filtered solutions were then poured into methanol (1 l.) for precipitation. In this way gel formation was prevented.

Attempted Preparation of Poly(3-O-vinyl-D-glucopyranose)

(a) With N hydrochloric acid at 100°

Poly(1,2:5,6-di-O-isopropylidene-3-O-vinyl-α-D-glucofuranose) ($[\eta]$ 0.41; 497 mg.) was heated at 100° for 2 hr. with N hydrochloric acid (10 ml.). Insoluble material was centrifuged, washed with water (2 x 15 ml.), ethanol (20 ml.) and ether (20 ml.), and dried to a white solid (242 mg., 48.7%). The centrifugate and water washings were neutralised with 2 N sodium hydroxide solution, dialysed overnight to remove chloride, and the solution concentrated under/...

under reduced pressure to small volume and finally freeze-dried. The syrupy product (44 mg.), dissolved in water (2 ml.), was poured into ethanol but no precipitate resulted.

Another portion of the poly(DIPG vinyl ether) (495.5 mg.) was similarly treated with N hydrochloric acid (10 ml.); the hydrolysate had $\alpha_D = +1.00°$ (1 dm.). Assuming a volume of 10 ml. and an equilibrium specific rotation of +52.7° for D-glucose, the rotation corresponded to 190 mg. glucose. The soluble portion (302.5 mg.) of the polymer on complete breakdown should give a calculated 190 mg. of glucose. The hydrolysate was deionised with Amberlite resins IR-120(H) and IR-45(OH) and chromatography in solvent system A with benzidine trichloroacetic acid spray showed only glucose to be present (R_f 0.225). The insoluble residue was soluble in chloroform and tetrachloroethane but insoluble in acetone. $[\alpha]_D$ 0.0° (c, 0.495). $[\eta]$ 0.12. Infrared analysis (Nujol mull) showed some OH absorption at 3500 $cm.^{-1}$ but the remainder of the spectrum resembled that of the original polymer. Further treatment of this residue (257 mg.) with N hydrochloric acid (10 ml.) at 100° for 2 hr. gave a hydrolysate with $\alpha_D + 0.74°$ (1 dm.), corresponding to 140 mg. of D-glucose, whereas in theory the solubilised portion (205 mg.) should yield 129 mg. glucose.

(b) With 50% (v/v) acetic acid

Treatment of the same poly(DIPG vinyl ether) with 50% (v/v) acetic acid/...

acid at 80° for 4 hr. solubilised only 3,6% of the polymer. When the same material (483 mg.) was hydrolysed with 50% (v/v) acetic acid (10 ml.) at 100° for 2 hr., the hydrolysate showed a rotation of + 0,27° (1 dm.) and the insoluble residue was 342 mg. (70,8%). The presence of glucose (R_f 0,28) in the solution was proved by chromatography in solvent system D with benzidine-trichloroacetic acid spray.

DISCUSSION

Introduction

The methacrylate ester of DIPG was the first derivative to be studied intensively. Methacrylates are known to be reactive and easy to polymerise by standard free-radical initiation, whereas allyl ethers, for example, are more difficult to homopolymerise and the product comprises very short chain lengths. Vinyl ethers, on the other hand, although reactive, require special techniques for both preparation and polymerisation, while a literature survey has already shown the lack of success attending the polymerisation of carbohydrate vinyl ethers. Acrylates can be grouped with methacrylates, but the former have been found to be slightly less reactive. Methyl groups in general tend to enhance the reactivity of monomers; e.g., methyl methacrylate is more reactive than methyl acrylate (Burnett, 1954). In case there should be difficulty in polymerising the bulky unsaturated derivatives of DIPG through steric or other factors, it seemed logical at the beginning to choose the derivative having the greater ease of polymerisation.

The preparation of a methacrylate is in theory a straightforward esterification but the acid lability of DIPG requires an acid-free medium. For this, the method of preparation used by Treadway and Yanovsky (1945) is especially suitable, since it is carried out in pyridine, which acts both as solvent and acid acceptor:-

Alcohol/...

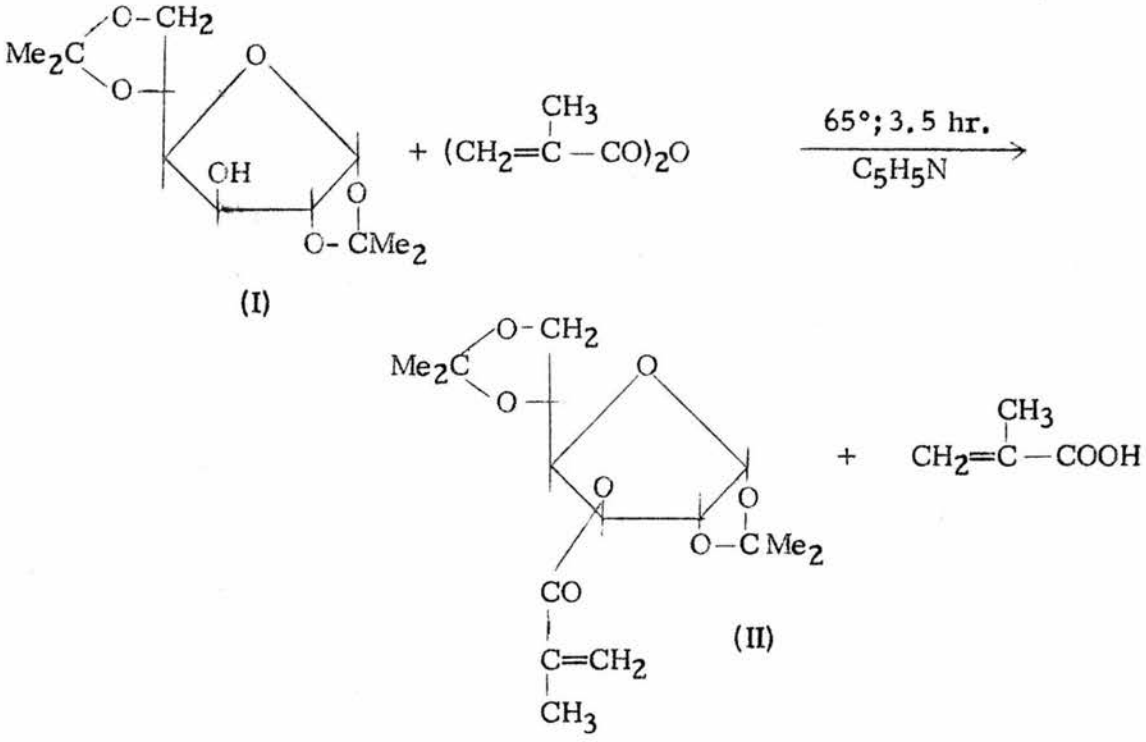
$$ROH + [CH_2{=}C(CH_3)CO]_2O \xrightarrow[C_5H_5N]{65^\circ} ROCOC(CH_3){=}CH_2 + CH_2{=}C(CH_3)COOH$$

Alcohol — Methacrylic anhydride — Methacrylate ester — Methacrylic acid

The fact that complete esterification of a polyhydroxy compound, such as sucrose, has been achieved by this method suggests that it can be applied successfully to a compound containing a single free hydroxyl group, such as DIPG.

Preparation of 1,2:5,6-Di-O-isopropylidene-3-O-methacryloyl-α-D-glucofuranose (II) (DIPG methacrylate).

Small-scale preparations of monomer using Treadway and Yanovsky's (1945) method gave the ester (II) as a viscous syrup in good yield (68.5%) simply by pouring the reactants into cold water, extraction with light petroleum, evaporation of the extract and high vacuum distillation in the presence of hydroquinone inhibitor:-



The/...

The preparation became more difficult on a larger scale when extensive gelling occurred during either concentration of the light petroleum extract or the final distillation of the product. This was found to be due to polymerisation of residual methacrylic anhydride, which was shown qualitatively not to be immediately hydrolysed with boiling water or cold dilute alkali. In the improved procedure reported (p. 21) the excess anhydride was removed by prolonged treatment with water and thorough washing with dilute alkali, while care was taken to introduce inhibitor before the light petroleum extract was concentrated.

A further difficulty was encountered when different samples of monomer were polymerised under identical conditions to polymers of widely varying yield and viscosity in experiments discussed in a later section (Tables 2 and 3 pp. 78-9). After repurification of the benzene solvent and recrystallisation of the benzoyl peroxide catalyst had failed to rectify this, attention was turned to the hydroquinone inhibitor when small hydroxyl peaks were observed to persist in the infrared spectra of samples of monomer repeatedly distilled with inhibitor (0.1%). As hydroquinone has m.p. 170.3° and is able to sublime 10° below the melting point, it was believed that the inhibitor was co-distilling with the monomer under the distillation conditions employed; replacement with tetrachlorohydroquinone (m.p. 238-40°) inhibitor eliminated the hydroxyl contamination in the infrared spectrum of the distilled monomer. As further indication of purity, samples of the colourless, syrupy product were/...

were also found to polymerise with a higher conversion and viscosity. Pure monomer was finally obtained in 50-70% yield, $[\alpha]_D$ - 32° in tetrachloroethane. It slowly crystallised to a solid mass, m.p. 34-5°.

This particular problem established the principle that, while physical properties such as the infrared absorption spectrum and the refractive index were useful guides, the prime criterion of monomer purity was its ability to undergo polymerisation in good yield and to a high viscosity value.

Monomer was also prepared in pyridine solution with methacryloyl chloride as an alternative to methacrylic anhydride as acylating agent, and by treating the 3-potassio salt of DIPG with methacryloyl chloride in light petroleum, but in both preparations the yield was inferior to that obtained by the pyridine-methacrylic anhydride method. Kimura and Imoto (1961) have also synthesised this monomer by treating DIPG in chloroform/pyridine solution with methacryloyl chloride, keeping the temperature below 10°. The colourless syrup obtained in 37% yield was distilled under high vacuum in the presence of picric acid inhibitor and the final product had $[\alpha]_D$ - 29° in benzene.

Since it might be possible to polymerise 3-O-methacryloyl-D-glucose directly, efforts were made to remove the isopropylidene groups from DIPG methacrylate without loss of the ester group. Acid hydrolysis at 100° was too severe even when the concentration of the sulphuric acid used was reduced to 0.01 N, and the hydrolysate was shown by chromatography to contain glucose/...

glucose and two other reducing substances, one of which was probably the 3-O-methacryloyl derivative. In view of this instability, no attempt was made to prepare this ester on the large-scale.

Polymerisation of 1,2:5,6-Di-O-isopropylidene-3-O-methacryloyl-α-D-gluco-furanose (II)

Benzoyl peroxide and azobisisobutyronitrile are the two catalysts most commonly used to initiate bulk or solution polymerisation of vinyl monomers of the type $CH_2{=}CXY$, where X usually = H or CH_3 and Y = Cl, COOMe, C_6H_5, etc.; at temperatures of 80° and 70° respectively, both break down at an appreciable rate to free radicals which act as the initiating species for polymer chain formation:-

$$(C_6H_5COO)_2 \longrightarrow 2C_6H_5COO\cdot \longrightarrow 2C_6H_5\cdot + 2CO_2;$$

(Benzoyl peroxide)

$$(CH_3)_2(CN)C{-}N{=}N{-}C(CN)(CH_3)_2 \longrightarrow 2(CH_3)_2(CN)C\cdot + N_2$$

(Azobisisobutyronitrile)

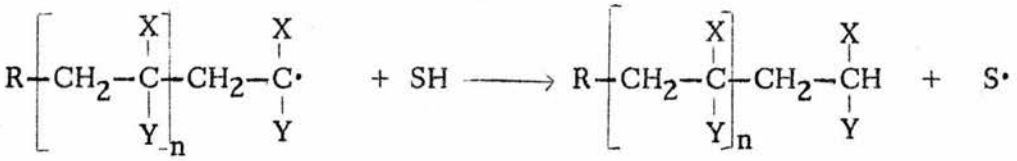
If R· represents the initiating radical, propagation proceeds:-

$$R\cdot + CH_2{=}CXY \longrightarrow R-CH_2-\overset{\overset{X}{|}}{\underset{\underset{Y}{|}}{C\cdot}}$$

$$R-CH_2-\overset{\overset{X}{|}}{\underset{\underset{Y}{|}}{C\cdot}} + CH_2{=}CXY \longrightarrow R-CH_2-\overset{\overset{X}{|}}{\underset{\underset{Y}{|}}{C}}-CH_2-\overset{\overset{X}{|}}{\underset{\underset{Y}{|}}{C\cdot}} \quad \text{etc.}$$

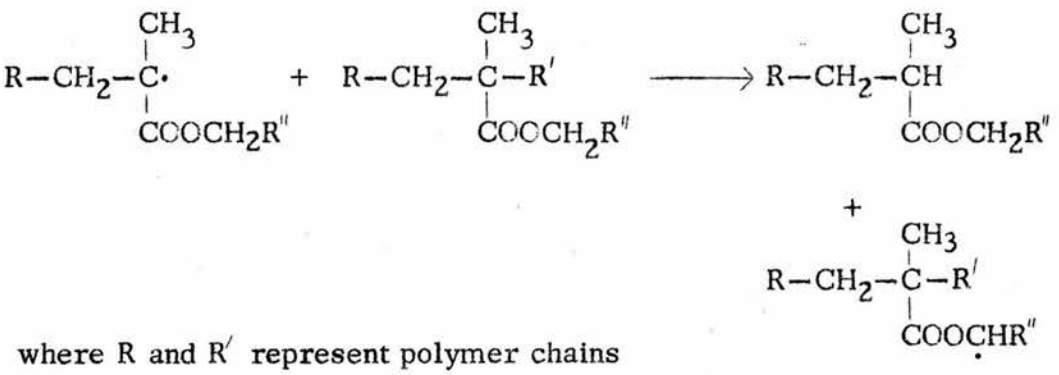
Termination occurs when the reactive end of a growing chain collides with another reactive radical, growing chain, impurity or solvent molecule (SH), for/...

for example, containing a reactive hydrogen atom:-



Benzoyl peroxide and azobisisobutyronitrile were both employed in polymerising DIPG methacrylate.

Although difficulty was experienced in dispersing the solid catalyst in the viscous monomer, the ester was readily polymerised in bulk with 1% benzoyl peroxide at 80° to a hard, transparent, Perspex-type plug, insoluble in chloroform. Cross-linking is known to occur in bulk polymerised methacrylates, probably brought about by a chain-transfer mechanism involving the abstraction of an active hydrogen from another terminated chain (Riddle, 1954):-



where R and R′ represent polymer chains

In an effort to obtain a more tractable product, solution polymerisation was studied on a 500 mg. scale with benzoyl peroxide catalyst at 80° in benzene, a solvent of low chain transfer reactivity.

Table 1/...

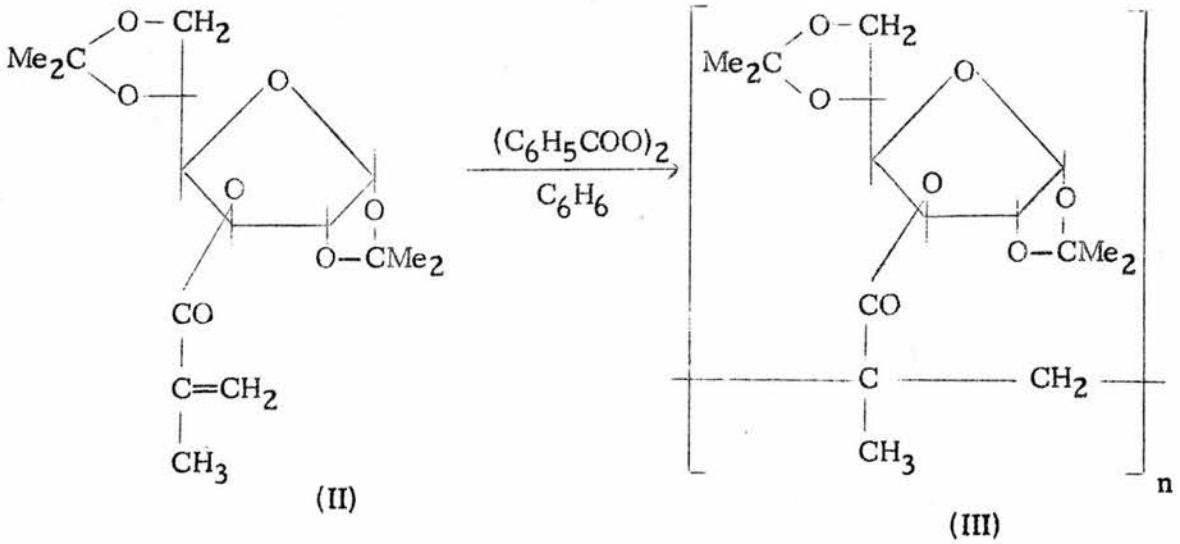
Table 1

Effect of Monomer Concentration on Polymer Yield

Expt. No.	Monomer:benzene ratio (w/v)	% Benzoyl peroxide (calc. on monomer)	Reaction Time at 80° (hr.)	% Conversion
1	1:20	0.1	5	0.0
2	1:20	1.0	5	0.0
3	1:10	2.0	90	2.9
4	1:1	1.0	19	50.1
5	1:1	1.0	19	57.5

Polymerisation did not proceed significantly in dilute solution (experiments 1 - 3), presumably because the cloud of solvent molecules around each free radical effectively prevented collisions with monomer molecules and thus propagation of a chain. However, polymerisation in concentrated solution was found to be much more effective (4). When repeated in (5) on a 1 g. scale, a 1:1 (w/v) ratio of monomer to benzene with 1% benzoyl peroxide at 80° for 19 hr. gave a white polymer in 57.5% yield after precipitation in methanol. The product was soluble in chlorinated hydrocarbons and benzene but insoluble in alcohol and water. Elementary and infrared analyses agreed well with the structure of poly(1, 2:5, 6-di-O-isopropylidene-3-O-methacryloyl-α-D-glucofuranose) (III), confirming that polymerisation had occurred without loss of the isopropylidene groups:-

(II)/...



(II) (III)

The absence of the small (C=C) absorption peak at 1640 cm^{-1} (Davison and Bates, 1953) was especially noted in the infrared spectrum of the polymer, as in Appendix I.

The specific rotation (-49° in tetrachloroethane) of the polymer was more negative than that of the monomer (-32° in tetrachloroethane) and similar values had been obtained consistently for polymers of varying inherent viscosity (0.15-0.50) prepared both by benzoyl peroxide and azobisisobutyronitrile catalysis. This effect has been widely recognised in synthetic polymers containing asymmetric centres both in and out of the main chain and is generally ascribed to the existence in dilute solution of a regular right- or left-handed helical configuration in the polymer chain; synthetic optically active polymers have recently been reviewed by Takebayashi and Minoura (1961). Of particular interest is the paper by Arcus and West (1959) on the enhanced optical activity

of/...

of the free-radical initiated polymer from (+)-1,3-dimethylbutyl methacrylate. In another review (1962) Arcus suggests that dissymetric coiling arises from the steric requirements of the bulky asymmetric side groups. The consistent value of the rotation for a given temperature and solvent infers that the coiling is a stable and constant feature of the polymer chain.

Further series of comparative, small-scale polymerisation experiments established that in concentrated solution a 1% catalyst concentration was optimal for both yield and viscosity.

Table 2

Effect of Catalyst Concentration on Polymer Yield and Viscosity

(monomer:benzene ratio 1:1 (w/v) at 80° for 24 hr.)

Expt. No.	% Benzoyl peroxide (calc. on monomer)	% Conversion	$[\eta]$	P. M. T. (°C)	$[\alpha]_D$ (c, 0.5)
1	0.2	24.8	0.22	194-8	-41.6°
2	1.0	60.0	0.52	197-200	-49.0°
3	5.0	50.2	0.15	192-6	-46.1°

Table 3/...

Table 3

Effect of Inhibitors, Catalysts and Impurities on Polymer Yield and Viscosity

(monomer:benzene ratio 1:1 (w/v); 24 hr. at the temperature appropriate to the catalyst 1%)

Expt. No.	Catalyst	% Conversion	$[\eta]$	$[\alpha]_D$ (c, 0.5)
1	Benzoyl peroxide (80)	58.0	0.25	-49.4°
2	Benzoyl peroxide (80)	6.0	-	-
3	Azobisisobutyronitrile (70)	40.0	0.26	-49.5°
4	Benzoyl peroxide (80)	40.3	0.17	-48.7°
5	Azobisisobutyronitrile (70)	41.8	0.22	-48.5°
6	Azobisisobutyronitrile (70)	77.5	0.25	-47.8°
7	Benzoyl peroxide (80)	76.4	0.42	-48.9°

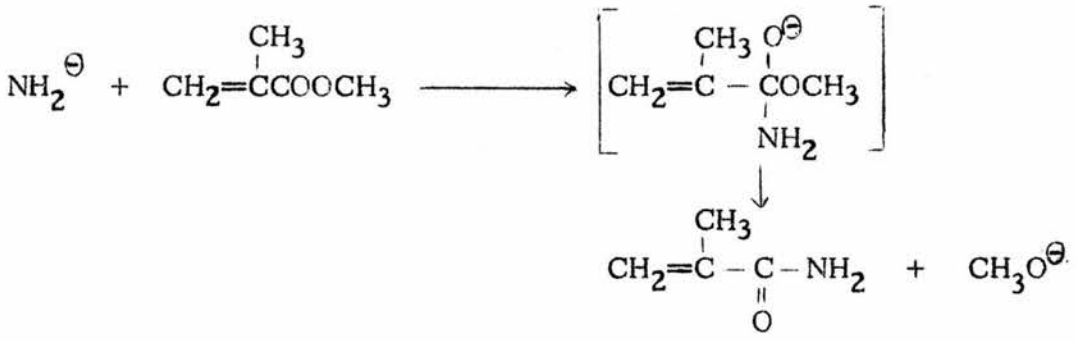
In expt. 1, when the preparation was repeated on a 5 g. scale to provide polymer for further study, % conversion and viscosity differed from that found previously (Table 2, expt. 2). Similarly, monomer prepared from the potassium salt and methacryloyl chloride (p. 22) polymerised with a very low conversion (2). This was found to be due to excess of hydroquinone inhibitor used in distillation of the monomer; tetrachlorohydroquinone was used in all subsequent preparations. Experiments 3-5, carried out on a sample of crystalline monomer, showed that 1% azobisisobutyronitrile at 70° was a slightly better catalyst than 1% benzoyl peroxide at 80°. In (5) the benzene used as solvent had been freshly purified in an attempt to improve the % conversion and viscosity of the polymer. When monomer/...

monomer was repurified by redistillation (6), the % conversion improved. In expt. 7 intensive purification, including washing with 5% sodium hydroxide solution, drying (sodium sulphate) and redistillation, resulted in polymer with a higher viscosity.

It has been established (Pepper, 1954) that certain vinyl monomers, e.g. acrylonitrile, methyl methacrylate, vinyl acetate, styrene, etc., can be polymerised both by free radicals and by anionic catalysts such as alkali metals, alkali metal alkoxides, alkali metal amides and organometallic compounds. On the other hand, monomers such as alkenes, styrene, alkyl vinyl ethers, etc., can be polymerised by cationic catalysts such as mineral acids (H_2SO_4, HCl, etc.) and Friedel-Crafts halides ($ZnCl_2$, BF_3, $AlCl_3$, etc.), which are all Lewis acids in that they are electron acceptors. Methyl methacrylate can be polymerised both by free radicals and by anionic catalysts but not by cationic catalysts, while vinyl ethers can only be polymerised by cationic catalysts; styrene can be polymerised by all three types.

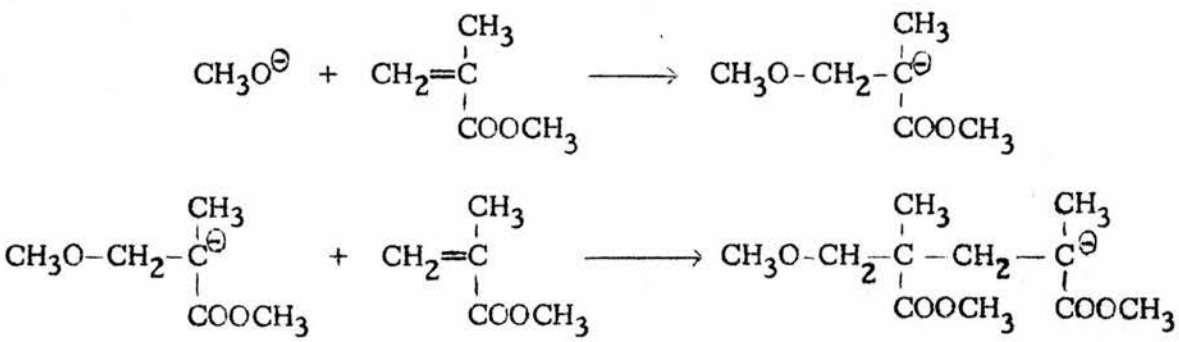
The anionic polymerisation of styrene initiated by potassium amide in liquid ammonia was studied by Higginson and Wooding (1952) who concluded that polymerisation was initiated by the amide ion $NH_2^{\ominus}$ and terminated by proton transfer from the solvent ammonia. Goode et al. (1960) decided that the mechanism of methyl methacrylate polymerisation initiated by metal amides in liquid ammonia was different from that of styrene because the polymer did not contain terminal amino-groups. They postulated that the initiating/...

initiating species was the methoxide ion, produced together with methacrylamide by the addition of amide ion to the monomer:-



Methacrylamide

Propagation then proceeded:-



etc.

At high potassium amide concentrations conversion to polymer decreased and methacrylamide was isolated, confirming that the initial $NH_2^{\ominus}$ addition does occur. The ability of sodium methoxide to initiate polymerisation in liquid ammonia was also demonstrated, the resulting polymer having a negligible nitrogen content.

The anionic polymerisation of DIPG methacrylate has been investigated for comparison with the free radical polymerisation previously described. On the basis of the mechanism outlined above, the initiating species would be the bulky DIPG alkoxide ion.

Table 4/...

Table 4

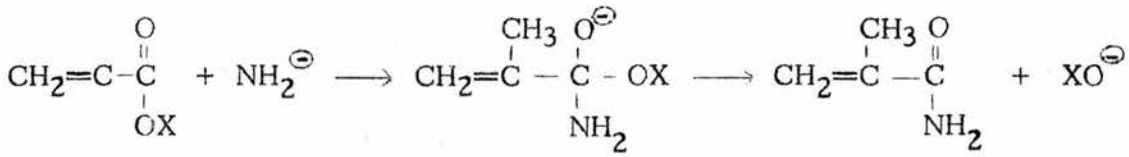
Anionic Polymerisations with Metal Amides in Liquid Ammonia

Expt. No.	Monomer	Metal amide (mmol.)	% Conversion	P. M. T. (° C)	$[\eta]$	$[\alpha]_D^{24}$	% Yield of DIPG
1	Methyl methacrylate	KNH_2 (1.8)	60.5	150-2	0.14	-	-
2	DIPG methacrylate	KNH_2 (1.8)	0.0	-	-	-	55.0
3	DIPG methacrylate	$LiNH_2$ (3.5)	5.6	188-90	0.16	-32.0°	62.1
4	DIPG methacrylate	$Ba(NH_2)_2$ (1.0)	2.3	192-6	0.31	-33.0°	39.9
5	DIPG methacrylate	KNH_2 (0.20)	1.3	163-6	-	-	48.5

The results in the above table show that, while a suspension of potassium amide in liquid ammonia polymerised methyl methacrylate successfully in 60.5% yield (expt. 1), it failed completely to polymerise DIPG methacrylate and led to a 55% recovery of DIPG (2). Only 6% conversion of monomer to polymer and 62% recovery of DIPG was obtained using lithium amide (3), which had been reported to give polymethyl methacrylate of high-molecular weight (Goode et al., 1960). The same authors reported that the alkaline earth metal amides and barium amide in particular were even more effective. As a weaker base, barium amide seemed less likely to cause ammonolysis of the monomer and indeed the formation of the amide took significantly longer than that of the alkali metal amides in expt. 4. Conversion to polymer was again very low, however, and a similar result was noted when a much reduced concentration of potassium amide was employed in an attempt to reduce ammonolysis (5).

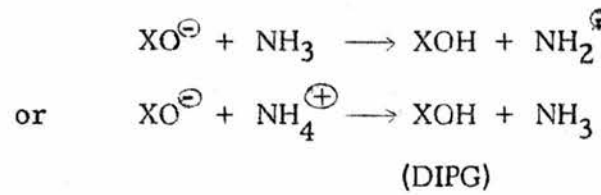
A/...

A probable explanation for these results is that the DIPG alkoxide ion is formed together with methacrylamide in the manner postulated by Goode and his coworkers:-



where X = DIPG residue methacrylamide

The bulky DIPG alkoxide ion is prevented from reacting with monomer to an appreciable extent either by steric hindrance or by relative lack of mobility and is eventually converted to DIPG by proton transfer from solvent ammonia or added ammonium chloride:-



(DIPG)

The overall reaction is the ammonolysis of the sugar ester to form methacrylamide and DIPG, which is analagous to the hydrolysis of an ester by hydroxyl ion in aqueous solution.

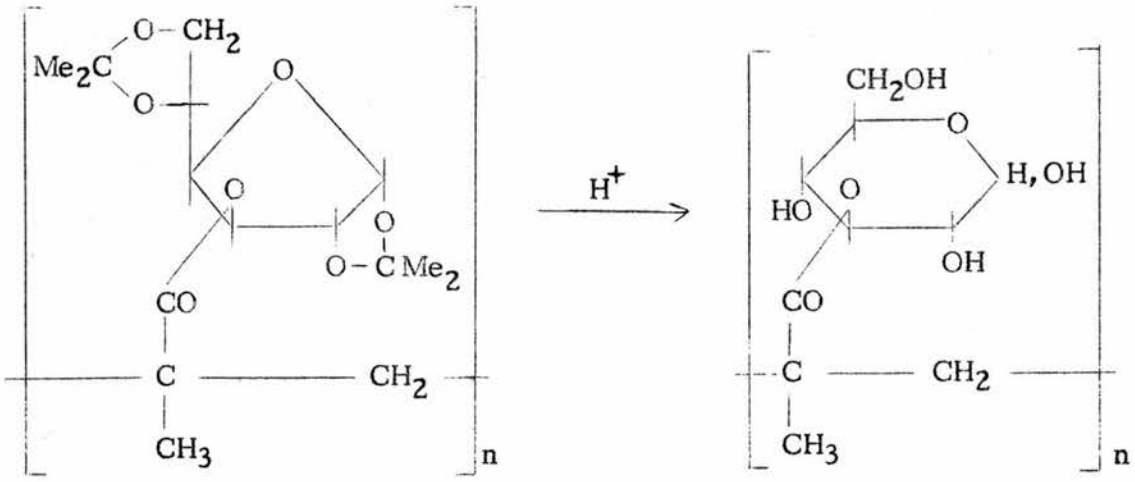
As a result of these findings, the larger-scale preparation of poly(DIPG methacrylate) was carried out by free radical polymerisation in benzene solution using 1% azobisisobutyronitrile catalyst at 70° for 24 hr. The reprecipitated polymer, obtained in 76% yield with an inherent viscosity of 0.50, analysed satisfactorily for the structure already indicated (III). Kimura and Imoto (1961) polymerised the monomer in more dilute benzene solution with 0.1% azobisisobutyronitrile at 40 or 50° and precipitated the polymer in methanol.

The yields in the four experiments quoted ranged from 13-64% for relatively short periods of polymerisation (1 - 3.5 hr.). Although the viscosity values given could not be interpreted because the units were not defined, specific rotations for the polymers were shown to vary from -36→ -42°. This was corrected in a later publication (Imoto and Kimura, 1962) in which they pointed out that the specific rotation was constant (ca. -48°) and independent of molecular weight, an effect discussed previously (p. 77). Other characteristics of the polymers, e.g. polymer melt temperature, analysis and solubility in organic solvents such as benzene, acetone and chloroform, were similar to those of the polymers reported in the Experimental section.

Preparation and Properties of Poly(3-O-methacryloyl-D-glucose) (IV)

Wolfrom et al. (1958) succeeded in deacetonating the polymer formed from 1,2:5,6-dianhydro-3,4-O-isopropylidene-D-mannitol and piperazine by removing the isopropylidene group with N hydrochloric acid at 100°. These conditions were applied to the polymer obtained from DIPG methacrylate and hydrolysis for 17 hr. in a preliminary experiment resulted in deacetonation and solubilisation of the polymer with some darkening of the resulting solution. When the period of hydrolysis at 100° was reduced to 2 hr., at which time the rotation was constant, no darkening of the solution occurred; neutralisation was carried out with anion-exchange resin and the polymer was obtained after precipitation in ethanol in 51% yield:-

(III)/...



(III) (IV)

The positive rotation ($[\alpha]_D$ + 45° in water) indicated that (IV) had a pyranose structure. The polymer had an inherent viscosity of 0.17 and its molecular weight as determined by viscosity and sedimentation measurements was approximately 43,000.

In the large-scale preparation with 20 g. of poly(DIPG methacrylate) (η 0.50), an improved working-up procedure was employed to avoid the use of the ion-exchange resin which tended to retain polymer, and reduce the yield. After hydrolysis, the acid was neutralised with alkali and ions removed by dialysis, which also removed low-molecular weight material. After a second acid hydrolysis, 16% of the poly(DIPG methacrylate) still remained insoluble and was regarded as cross-linked material. The white, powdery polymer (IV) was isolated in 74% yield, with an inherent viscosity of 0.42 and molecular weight determined as before of approximately 100,000. The specific rotation (+50° in water) and elementary analysis were in good agreement with the poly(3-O-methacryloyl-D-glucopyranose) structure (IV) proposed.

Kimura/...

Kimura and Imoto (1961) deacetonated poly(DIPG methacrylate) with N sulphuric acid at 100° for 48 hr. The water-soluble polymer isolated in 48% yield had a specific rotation of +56° in water and the same viscosity value as the acetonated polymer.

A quantitative determination of reducing power of the deacetonated polymer with sodium hypoidite (Hirst et al., 1949) gave a value of 94.5%, compared to 97.3% for 3-O-methyl-D-glucose, which confirmed the presence of the potential free reducing group in poly(3-O-methacryloyl-D-glucose) (IV). The polymer, however, exhibited a negligible reducing power (1.9%) towards Somogyi copper reagent (Somogyi, 1952), a value very much less than that (46.7%) for 3-O-methyl-D-glucose (Table 5).

Table 5

Reducing Power of Poly(3-O-methacryloyl-D-glucose) and Standard Sugars

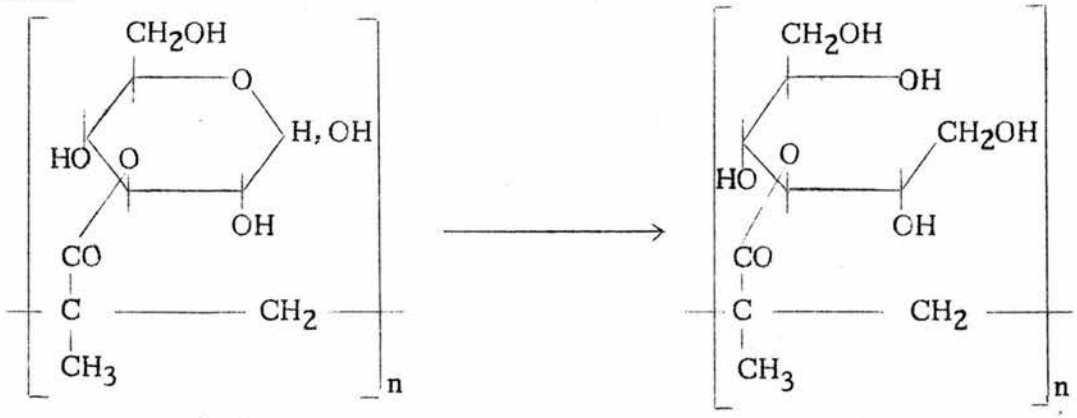
Compound	Reduction Equivalent	% Reducing Power
D-Glucose	5.95	100
2-O-Methyl-D-glucose	0.35	5.8
3-O-Methyl-D-glucose	2.59	46.7
6-O-Methyl-D-glucose	5.18	87.1
Poly(3-O-methacryloyl-D-glucose)	0.11	1.9

In this nonstoichiometric reaction, the position of the substituent group is important, e.g. 6-O-methyl-D-glucose showed 87.1% of the reducing power of glucose, whereas 2-O-methyl-D-glucose showed only 5.8%. Another factor involved in the case of poly(3-O-methacryloyl-D-glucose) is the increased steric effect of the bulky methacryloyl group and the polymer chain. Despite its/...

its low reducing power towards the Somogyi reagent, the polymer was strongly reducing to Fehling's solution.

Before attempting the reduction of poly(3-O-methacryloyl-D-glucose), the model compound 3-O-methyl-D-glucose, prepared from DIPG by the method of Glen et al. (1951), was reduced with hydrogen and Raney nickel as recommended by Dr. L. Hough (personal communication). The compound was reduced only very slowly with borohydride (Bragg and Hough, 1957). The syrupy product first obtained was found by analysis to contain 10% nickel, which was removed with ion exchange resins. The final syrupy product, 3-O-methyl-D-glucitol, obtained in 41% yield, had a very low positive rotation (+0.9° in water) and was chromatographically identical with an authentic sample.

To avoid the complications of nickel contamination, poly(3-O-methacryloyl-D-glucose) was reduced with sodium borohydride in aqueous solution and the reaction was followed polarimetrically. Non-reducing poly(3-O-methacryloyl-D-glucitol) (V) was obtained in 76.5% yield with a low positive rotation:-



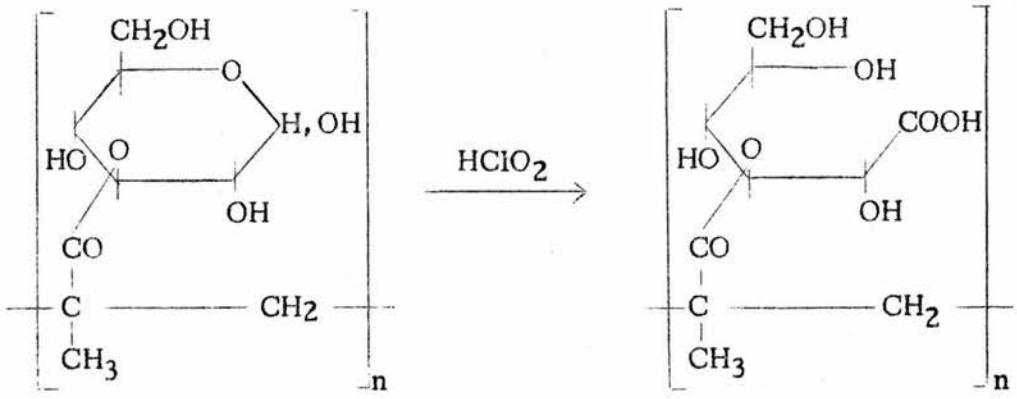
(IV) (V)

Oxidation of Poly(3-O-methacryloyl-D-glucose)

Oxidation in aqueous solution with bromine was first tried but the reaction was still incomplete after 4 weeks, as the solution was still strongly reducing. Attention was then turned to chlorous acid which is a specific oxidant for aldehydic groups in carbohydrates (Jeanes and Isbell, 1941).

Davidson and Nevell (1955) made a detailed study of the conditions of chlorous acid oxidation of aldehydic groups in periodate oxycelluloses and concluded that maximum conversion of aldehydic to carboxyl occurred at 20° at pH 3 with chlorite concentration and time of reaction depending on the extent of oxidation of the cellulose sample. When these general conditions were applied to the oxidation of the deacetonated polymer, preliminary experiments showed that treatment at 20° for 24 hr. with a solution 0.4 M in sodium chlorite and 2 M in acetic acid effected almost complete oxidation and the product obtained on precipitation with ethanol showed no reducing properties. Oxidation on the 0.5 g. scale was followed polarimetrically ($[\alpha]_D$ 0.0°; constant) and the solution was dialysed and treated with a cation-exchange resin to give poly(3-O-methacryloyl-D-gluconic acid) (VI) in 91% yield, containing 83% of the theoretical carboxyl content:-

(IV)/...



(IV) (VI)

The sodium salt of (VI) was obtained as a white solid with an inherent viscosity of 0.47 in water and with a low positive rotation ($[\alpha]_D$ + 3°). A concentrated solution in water was notably viscous and did not retrograde quickly as did solutions of the free acid. Accordingly, the sodium salt was used in a series of experiments to determine whether insoluble salts could be prepared. In this respect, the properties of the synthetic polymer acid might resemble those of the naturally occurring polyuronic acids, such as alginic acid. The alkali metal alginates are water-soluble and give viscous solutions of commercial importance, but precipitation occurs with polyvalent cations and heavy monovalent cations such as silver (McDowell, 1955). Table 6 below shows that the sodium salt of (VI) leads to insoluble salts with various polyvalent cations, notably the bivalent calcium, barium, copper and lead, and gives a slight precipitate with silver.

Table 6/...

Table 6

Salts of Poly(3-O-methacryloyl-D-gluconic acid)

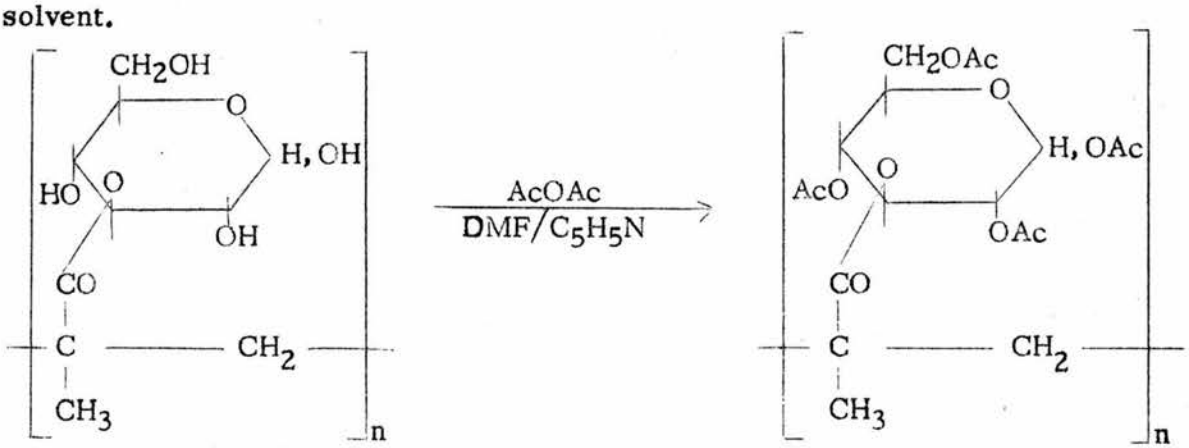
Cation	Salt added	Precipitation*
K^+	KCl	-
NH_4^+	NH_4Cl	-
Ag^+	$AgNO_3$	+
Ca^{2+}	$CaCl_2$	++
Mg^{2+}	$MgSO_4.7H_2O$	-
Ba^{2+}	$BaCl_2$	+++
Cu^{2+}	$CuSO_4.5H_2O$	++
Pb^{2+}	$Pb(OAc)_2.3H_2O$	+++
Fe^{2+}	$FeSO_4.7H_2O$	+
Ni^{2+}	$NiCl_2.6H_2O$	+
Co^{2+}	$CoCl_2.6H_2O$	+
Fe^{3+}	$FeCl_3$	+
Al^{3+}	$Al_2(SO_4)_3.18H_2O$	+

*Heavy (+++), medium (++), slight (+), none (-)

Preparation of Esters and Ethers of Poly(3-O-methacryloyl-D-glucose) (IV)

An attempt at acetylating a freshly precipitated sample of poly(3-O-methacryloyl-D-glucose) with pyridine and acetic anhydride in the manner described by Black and Dewar (1954) for laminarin led to a poor yield of the acetylated/...

acetylated derivative. The use of dimethylformamide to dissolve the deacetonated polymer (Schlubach and Repenning, 1959) enabled the reaction to proceed homogeneously, allowing the fully acetylated poly(1, 2, 4, 6-tetra-O-acetyl-3-O-methacryloyl-D-glucopyranose) (VII) to form in 79% yield. The rotation ($[\alpha]_D$ + 43°) indicated an $\alpha\beta$ mixture, while the inherent viscosity (0.38) was of the same order as that of the deacetonated polymer (0.50) in the same solvent.

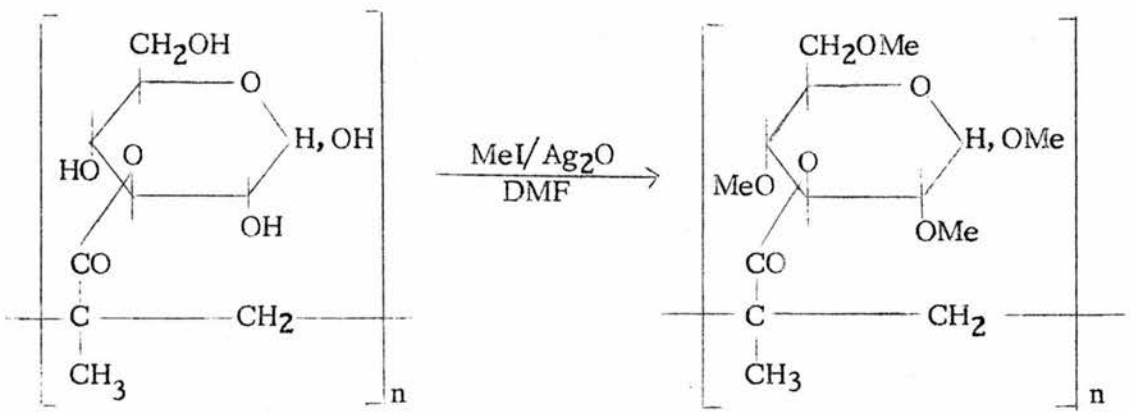


(IV) (VII)

The tetraacetate, a white powder, was soluble in chloroform, acetone, dimethylformamide, dimethylsulphoxide, ethyl acetate, benzene and acetic acid. An attempt was made to convert this derivative (VII) to poly(2, 4, 6-tri-O-acetyl-3-O-methacryloyl-D-glucopyranosyl bromide) as an intermediate for the preparation of the methyl glucoside in a Koenigs-Knorr reaction. After treatment with hydrobromic acid in glacial acetic acid, working up was made difficult by extensive emulsion formation, and the resulting product contained only half the theoretical acetyl and bromine contents.

The/...

The deacetonated polymer was methylated with silver oxide and methyl iodide in dimethylformamide solution (Kuhn et al., 1955) but the product after exhaustive methylation had a slightly low methoxyl content (36.0%) for the fully methylated poly(methyl 3-C-methacryloyl-2,4,6-tri-O-methyl-D-gluco-pyranoside) (VIII), theoretical value 40.8%:-



(IV) (VIII)

A recent paper by Walker et al. (1962) justifies this methylation of a reducing carbohydrate without protecting the reducing group by glycosidation. They claim that the preferential methylation of the hemi-acetal hydroxyl group is essentially complete in one hour at room temperature, so that glycosidation occurs more rapidly than competing side reactions, especially oxidation in the presence of silver oxide. They note, however, that methylation of the remaining hydroxyl groups takes much longer and traces of incompletely methylated product persist, even after 40 hr., if no new reagents are added.

Poly(3-O-methacryloyl-D-glucose) readily reacted with phenyl isocyanate in dimethylformamide solution (Bouveng, 1961) yielding a product which analysed satisfactorily as poly(3-O-methacryloyl-tri-O-phenylcarbamoyl-D-glucose), in 77% yield and with an inherent viscosity of 0.32.

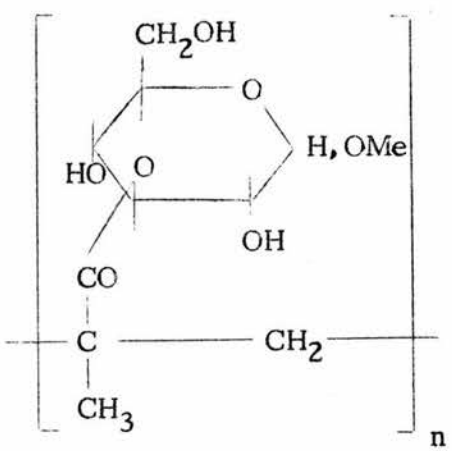
$$ROH + PhNCO \longrightarrow ROCONHPh$$

(Phenylcarbamate)

It is probable that substitution of one of the hydroxyls is prevented by the unfavourable steric factor of the bulky phenylcarbamoyl groups.

Preparation of Derivatives at C(1) of Poly(3-O-methacryloyl-D-glucose) (IV)

Poly(3-O-methacryloyl-D-glucose) (IV), on treatment with hot 1.5% methanolic hydrogen chloride, formed poly(methyl 3-O-methacryloyl-D-glucopyranoside) (IX) in 64% yield:-

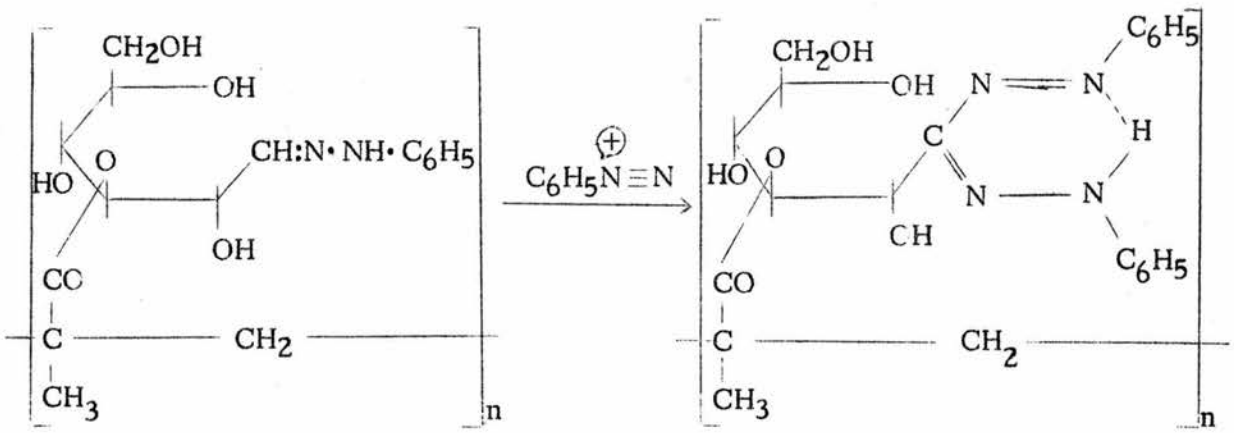


(IX)

This reaction was heterogeneous; the low yield was due to some of the polymer dissolving in the reaction medium, which indicated that some degradation was occurring.

The/...

The deacetonated polymer also reacted in acetic acid solution with phenylhydrazone (Barry and Mitchell, 1954) to give a phenylhydrazone (X) in 75% yield, which then reacted with phenyldiazonium chloride in pyridine-ethanol to form the brilliant red, insoluble diphenylformazan (XI) (Mester and Major, 1955):-

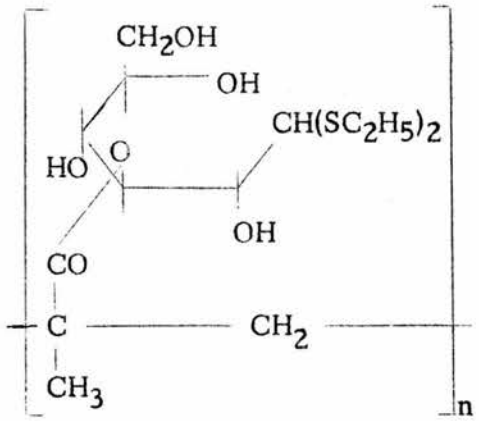


(X) (XI)

The nitrogen content (8.4%), however, was significantly low for the deacetonated polymer diphenylformazan [(XI); N, 12.7%] indicating that only some of the reactive hydrogen atoms in the phenylhydrazone (X) had reacted to form the diphenylformazan. This may be attributed to the insolubility of the polymeric diphenylformazan, so that the product is precipitated before the reaction is complete.

A similar result was obtained when an attempt was made to prepare the diethyl dithioacetal of poly(3-O-methacryloyl-D-glucose) (XII) with ethanethiol in concentrated hydrochloric acid solution at 0° using the method of Wolfrom and Karabinos (1945):-

(XII)/...



(XII)

Two products were isolated, but the sulphur contents (9.3%) were only half of the theoretical value (18.1%) for the diethyl dithioacetal structure (XII).

The reactions outlined above have given ample proof of the presence of potential reducing groups in the deacetonated polymer, confirming structure (IV), but solubility difficulties, especially premature precipitation of the product, have prevented complete reaction. In this respect, preparation of derivatives at C(1) compares badly with that of the other derivatives of poly(3-O-methacryloyl-D-glucose) previously described, but it is noteworthy that the other reactions were carried out completely in solution and precipitation from the reaction medium did not occur.

Preparation of 3-O-Allyl-1,2:5,6-di-O-isopropylidene-α-D-glucofuranose (XIII) (DIPG allyl ether)

The preliminary preparation of the 3-O-allyl ether was undertaken to gain experience in syntheses of unsaturated derivatives of DIPG, since the literature survey indicated that allyl ethers of carbohydrates could be readily synthesised. Indeed, Bladon and Owen (1950) listed three general methods for the preparation of mono-allyl ethers of substituted hexitols:-

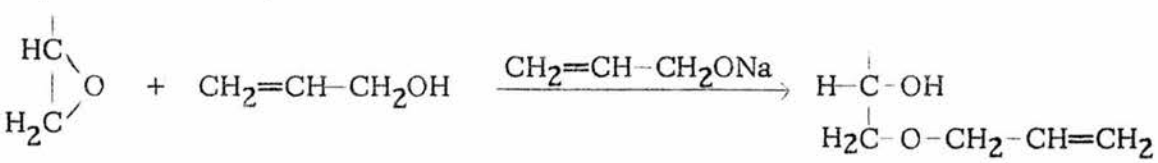
(a) Direct allylation of the derivative with allyl bromide in the presence of excess sodium hydroxide:

$$ROH + CH_2{=}CH{-}CH_2Br \xrightarrow{NaOH} RO{-}CH_2{-}CH{=}CH_2 + HBr$$

(b) Reaction of the sodium alcoholate (prepared by treatment with sodium in liquid ammonia) with allyl bromide:

$$RONa + CH_2{=}CH{-}CH_2Br \longrightarrow RO{-}CH_2{-}CH{=}CH_2 + NaBr$$

(c) Ring-opening of an ethylene oxide anhydro-compound with sodium allyl oxide and allyl alcohol:



Muskat (1934) had shown that DIPG could be methylated in 96% yield by treatment with potassium and methyl iodide in liquid ammonia; allylation was similarly attempted using method (b). The general procedure was first checked by carrying out the preparation of the methyl ether: repeated treatment/...

treatment of DIPG in liquid ammonia with sodium and methyl iodide enabled pure 1,2:5,6-di-O-isopropylidene-3-O-methyl-α-D-glucofuranose to be isolated in 78% yield. However, when DIPG was similarly treated with sodium and allyl chloride in liquid ammonia, no allyl ether was isolated. Instead, DIPG was recovered unchanged and the presence of allylamine was readily detected, indicating that the allyl chloride had reacted preferentially with the ammonia and the liberated hydrochloric acid caused the decomposition of the sodium salt:

$$\underset{\text{allyl chloride}}{CH_2{=}CH{-}CH_2Cl} + NH_3 \longrightarrow \underset{\text{allylamine}}{CH_2{=}CH{-}CH_2NH_2} + HCl$$

$$HCl + NH_3 \longrightarrow NH_4Cl$$

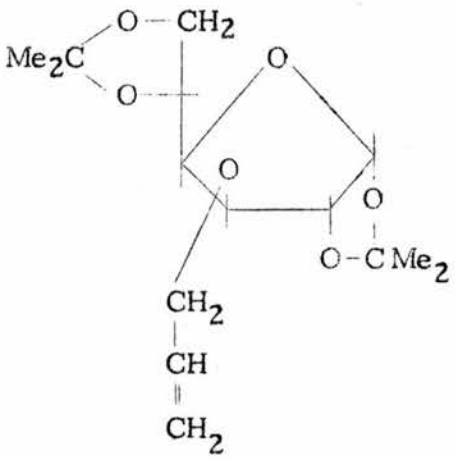
$$\underset{\substack{\text{3-sodio}\\ \text{salt of DIPG}}}{RONa} + NH_4Cl \longrightarrow \underset{\text{DIPG}}{ROH} + NaCl + NH_3$$

The synthesis, however, was accomplished by removal of the ammonia from the sodium salt before condensation with allyl chloride:

$$RONa + CH_2{=}CH{-}CH_2Cl \longrightarrow RO{-}CH_2{-}CH{=}CH_2 + NaCl$$

The sodium salt obtained by treatment of DIPG with sodium in liquid ammonia analysed as a true alkoxide, only slightly contaminated with ammonia (N, 0.19%). Reaction with allyl chloride in a sealed tube at 122° then formed 3-O-allyl-1,2:5,6-di-O-isopropylidene-α-D-glucofuranose (XIII) which was isolated as a colourless oil in 73% yield by high vacuum distillation:

(XIII)/...

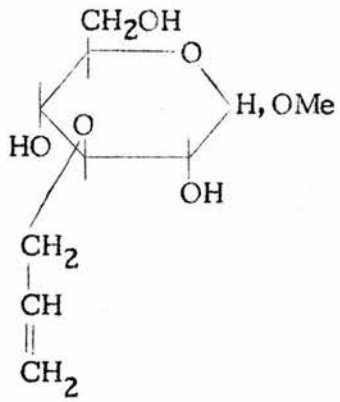


(XIII)

A second preparation was carried out by repeating the synthesis described by Corbett and McKay (1961), which was essentially Bladon and Owen's direct allylation method (a). A solution of DIPG in dioxan was treated with allyl bromide in the presence of powdered sodium hydroxide and, on working up, the colourless oil obtained in 94% yield ($[\alpha]_D$ - 29° in chloroform, - 27° in ethanol) was found to be similar in its physical characteristics to that prepared earlier. It differed from that of Corbett and McKay's preparation ($[\alpha]_D^{20}$ - 12.7° in chloroform) in its optical rotation. The sample was further purified by redistillation and it was noted that no hydroxyl absorption peak was present in the infrared spectrum.

A portion of the earlier product was deacetonated with sulphuric acid yielding syrupy 3-O-allyl-D-glucose ($[\alpha]_D$ + 24° in water) but chromatography of the product showed the presence of a small amount of glucose. Similar deacetonation/...

deacetonation of the later product, that prepared by Corbett and McKay's method, afforded 3-O-allyl-D-glucose, in quantitative yield, as a syrup which slowly crystallised and which was chromatographically pure. This suggests that the glucose found in the previous deacetonated product originated from contaminating DIPG in the DIPG allyl ether rather than from loss of allyl groups during deacetonation. The structure of the purer 3-O-allyl-D-glucose was confirmed by the immunity to periodate oxidation of its methyl glucopyranoside (XIV) which should be resistant to attack by periodate, having no vicinal diols in its structure (Bobbitt, 1956):-



(XIV)

Reduction of periodate was negligible for both the mono-O-allyl- and 3-O-methyl-D-glucopyranosides:-

Table 8/...

Table 7

Periodate oxidations of mono-O-allyl- and 3-O-methyl-D-glucosides

Time of oxidation (hr.)	Periodate uptake (moles/mole of glucoside)		Formic acid liberated (moles/mole of glucoside)	
	Mono-O-allyl-glucoside	3-O-Methyl-glucoside	Mono-O-allyl-glucoside	3-O-Methyl-glucoside
1	0.21	0.10	0.03	0.02
3	0.24	0.10	0.06	0.03
6	0.26	0.11	0.08	0.05
24	0.27	0.15	0.11	0.06
48	0.29	0.14	0.11	0.05

Polymerisation of 3-O-Allyl-1,2:5,6-di-O-isopropylidene-α-D-glucofuranose (XIII)

The purified monomer was subjected to free radical catalysis in an attempt to induce polymerisation. Monomer, both in bulk, i.e. undiluted, and in 1:1 (w/v) benzene solution, was heated at 80° for 24 hr. with 1, 5 and 10% benzoyl peroxide catalyst. Some evidence of polymerisation was seen in that the systems with 5% and 10% catalyst were more viscous after the reaction, but no polymer was precipitated by pouring into methanol, any polymer that had been formed being of too short a chain length to be insoluble. No attempt was made to study this low-molecular-weight material.

The result is not entirely unexpected as it is known that mono-functional allyl monomers can only be polymerised to short chain polymers. It/...

It is not generally appreciated, however, that the failure of allyl derivatives to polymerise to high molecular weights is due to the dominance of chain transfer reactions over normal chain propagation and not to lack of reactivity in the allyl double bond: the double bond of allyl alcohol ($CH_2{=}CH{-}CH_2OH$), for example, is only slightly less reactive than the double bond in vinyl acetate ($CH_2{=}CH{-}OCOCH_3$) (Brown and James, 1962) and that of the allyl ether of DIPG should be similar. The difference between the two monomers lies in the presence of an abstractable hydrogen in the methylene group alpha to the double bond in allyl alcohol and, in the case of allyl esters, in the methylene group alpha to the carbonyl in the acid residue (see reactions (1) and (2) below). Normal addition of a growing polymer radical ($R_n^{\bullet}$) to a monomer forms another vinylic radical of undiminished reactivity, able to carry on chain propagation:

$$R_n^{\bullet} + CH_2{=}CH(CH_2X) \longrightarrow R_n{-}CH_2{-}\dot{C}H(CH_2X) = R_{n+1}^{\bullet}$$

$$R_{n+1}^{\bullet} + CH_2{=}CH(CH_2X) \longrightarrow R_{n+1}{-}CH_2{-}\dot{C}H(CH_2X) = R_{n+2}^{\bullet}$$

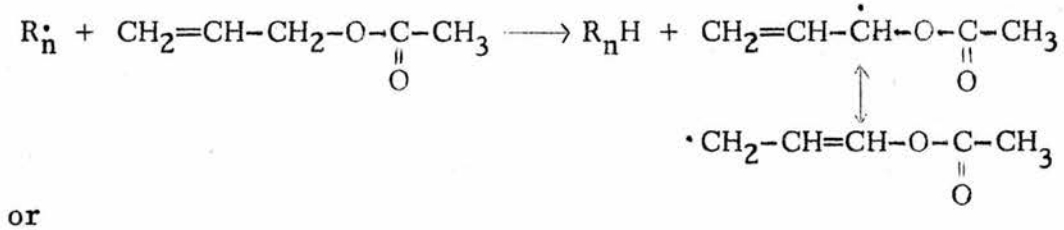
etc.

In allyl polymerisations metathesis (atom transfer) occurs in direct competition to this, forming a new radical, the allylic radical:

$$R_n^{\bullet} + CH_2{=}CH(CH_2X) \longrightarrow RH + CH_2{=}CH{-}\dot{C}HX$$

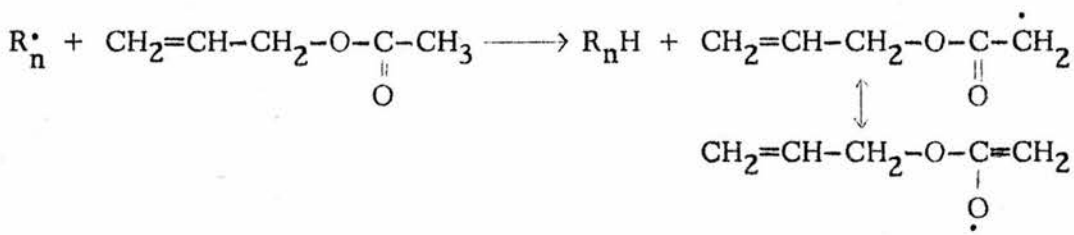
Commonly/...

Commonly this new radical is unreactive through resonance stabilisation and cannot propagate the chain, causing degradative chain transfer, as in the case of allyl acetate (Bartlett and Altschul, 1945):-



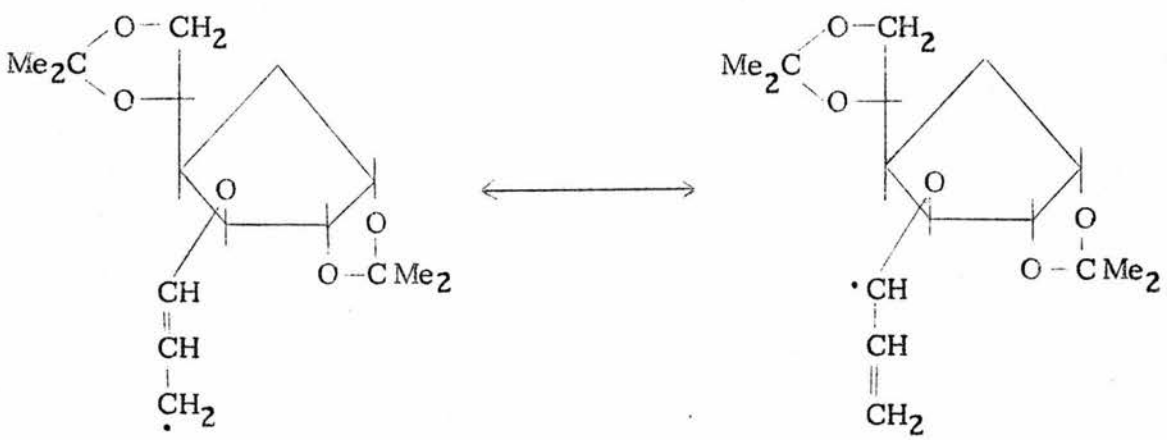
(1)

or



(2)

With allyl ethers, reaction (2), representing hydrogen abstraction from the methylene group alpha to the carbonyl, cannot arise; however, hydrogen abstraction is still possible from the methylene group alpha to the double bond, as in reaction (1). Similar metathesis from the allyl ether of DIPG will therefore leave the following allylic radical which, if sufficiently resonance stabilised, will not propagate a polymer chain:-



It/...

It is believed that the allylic radicals are mainly destroyed by dimerisation or by combination with a growing polymer radical. The overall effect is termination of growing polymer chains, causing low degrees of polymerisation (D.P.s).

In certain instances the allylic radical may be insufficiently resonance stabilised and thus can initiate new chains in effective chain transfer (Sakurada and Takahashi, 1954), which also tends to give low D.P.s. While this effect is generally negligible in comparison to degradative chain transfer (Litt and Eirich, 1960), it constitutes a larger proportion of the transfer reactions in suitably substituted allyl derivatives (Gaylord and Kujawa, 1959), as much as 85% in the case of α-methallyl acetate ($CH_2=CH-\underset{\displaystyle CH_3}{\underset{|}{CH}}-O-\underset{\displaystyle O}{\underset{\|}{C}}-CH_3$). Gaylord (1956), however, states that in both allyl ethyl carbonate ($CH_2=CH-CH_2-O-\underset{\displaystyle O}{\underset{\|}{C}}-OC_2H_5$) and allyl ethyl ether ($CH_2=CH-CH_2-OC_2H_5$), which possess only the allylic position for hydrogen abstraction, the resulting radical has little tendency to react further with monomer, whereas allyl esters possess in the second position a more reactive position capable of effective chain transfer.

Sakurada and Takahashi (1954) have also claimed that allyl ethers polymerise to lower D.P.s than allyl esters for the same catalyst concentration and that degradative chain transfer constituted 70% of their transfer reactions. At the same time they note that copolymerisation of allyl ethers and/...

and vinyl acetate occurred smoothly. This effect has been noticed with other allyl and vinyl monomers, including allyl acetate and maleic anhydride (Bartlett and Nozaki, 1946), and allyl alcohol and acrylonitrile (Oster and Mizutani, 1956). Evidently the allylic radical is capable of addition to vinyl monomers possessing polar groups which lower the activation energy for addition to the double bond (Brown and James, 1962).

A feature of the copolymer formed in each case is that each monomer regularly alternates along the polymer chain:-

$$-A-B-A-B-A-B-A-B-$$

This alternating effect has been reviewed by Burnett (1954) and further examples of alternating copolymerisation have recently been reported by Martin and Jensen (1962). If the principle is generally applicable, it is probable that the allyl ether of DIPG can also be copolymerised with suitable vinyl monomers to relatively high-molecular weight material. This interesting possibility has not been investigated as it is not considered to come within the scope of this work.

Vinylation of 1, 2:5, 6-Di-O-isopropylidene-α-D-glucofuranose

The preparation of 1, 2:5, 6-di-O-isopropylidene-3-O-vinyl-α-D-glucofuranose (DIPG vinyl ether) differed fundamentally from that of the allyl ether and the methacrylate ester in that the derivative was known from the beginning of this study, having been reported by Reppe et al. (1956) and Mikhant'ev and Lapenko (1957), as described in the Introduction. Both groups used acetylene at high pressure and at high temperatures (140-150°) in the presence of alkali for vinylation. Reppe's product was admitted to be impure although it did polymerise slightly; the Russian workers, on the other hand, reported satisfactory analysis figures for their product in agreement with the structure proposed; furthermore, they claimed that their derivative was hydrogenated to 1, 2:5, 6-di-O-isopropylidene-3-O-ethyl-α-D-glucofuranose in 77% yield. Nevertheless, the fact that polymerisation was not described suggests that the monomer was impure, possibly through slight contamination with side products of the reaction. Attempts were therefore made to synthesise the vinyl ether using milder reaction conditions and to ensure its high purity for polymerisation studies.

The facile reaction between the sodium salt of DIPG and allyl chloride (p. 44) prompted investigation of a similar reaction between the salt and vinyl chloride or bromide for the preparation of the vinyl ether. It was appreciated that different conditions would be required, since the halogen atom/...

atom in vinyl halides displays diminished reactivity due to partial double bond character in the carbon-halogen linkage (Fieser and Fieser, 1961). On the other hand, Reppe (1956) claimed that vinyl ethers could be formed from alcohols using vinyl chloride in the presence of alkali metal hydroxides or alcoholates; this was substantiated by Deutschman and Kircher (1961) in the vinylation of methyl α-D-glucopyranoside. Holly (1959) recommended the use of an alkali metal alcoholate rather than a hydroxide in the vinylation of tertiary alcohols, which are very difficult to vinylate.

A series of reactions was carried out in which the 3-sodio salt of DIPG was heated with excess vinyl chloride in a steel bomb for 2 hr. at different temperatures with the following results:-

Temperature (°C) :	60	100	120	140
% Reaction :	2.8	11.2	40.4	87.5

Below 100°, negligible reaction occurred; at 120°, 40% of the sodium had been converted to sodium chloride and at 140°, reaction was almost complete (87.5%). The reaction mixture was extracted with light petroleum (b.p. 60-80°) to extract any vinyl ether formed, since it was expected to be soluble in that solvent; extraction with ether then removed DIPG from the mixture. Results of the reaction at 140° (expt. 1) and others similarly conducted are recorded below, again using sodium chloride production as a measure of the percentage reaction:-

Table/...

Table 8

Reactions of DIPG salts with vinyl chloride or bromide

Expt. No.	Wt. of salt (mg.)	Reactants (10 ml.)	Reaction temp. (°C)	% Reaction	Light petroleum extract (mg.)	Ether extract (mg.)	% Yield of DIPG
1	734 (Na)	Vinyl chloride	140	87.5	65	509	75.2
2	254 (Na)	Vinyl chloride [+ NaOH(66 mg.)]	140	73.8	36	165	70.5
3	600 (K)	Vinyl chloride	100	80.3	32	436	83.3
4	476 (K)	Vinyl chloride	120	90.9	49	216	52.0
5	293 (K)	Vinyl bromide	80	70.4	44	196	76.7
6	360 (K)	Vinyl bromide	100	76.3	36	246	78.3

In expt. 1 the light petroleum extracts contained very little material whereas there was a 75% recovery of DIPG from the ether extract. It was therefore concluded that at 140° hydrogen chloride was split off from the vinyl chloride, reacting with the 3-sodio salt to form DIPG and sodium chloride:-

$$RONa + CH_2{=}CHCl \longrightarrow ROH + CH{\equiv}CH + NaCl$$

3-sodio salt of DIPG — vinyl chloride — DIPG — acetylene — sodium chloride

The introduction of powdered sodium hydroxide to counteract the hydrogen chloride failed to prevent the production of DIPG (2). Other experiments were carried out with the 3-potassio salt of DIPG since it was expected to be more reactive than the sodium salt; it reacted with vinyl chloride at a lower/...

lower temperature than the sodium salt, but the main product was still DIPG (83% at 100°) (3). At 120° the same reactants formed only 52% DIPG, but there was no corresponding increase in the light petroleum extract (4). With vinyl bromide, reaction occurred at still lower temperatures (80° and 100°) to form DIPG in 77-8% yield (5,6). Evidently the halogen atom in vinyl halides is removed by dehydrohalogenation in the presence of sodium and potassium salts of DIPG; acetylene must also be formed during the course of the reaction. Use was made of this in three further experiments carried out under more drastic conditions similar to those employed by Mikhant'ev and Lapenko (1957):-

Table 9

Reactions of DIPG with vinyl chloride and potassium hydroxide

Expt. No.	DIPG (g.)	Vinyl chloride (ml.)	Potassium hydroxide (g.)	Dioxan (ml.)	Reaction temp. (°C)	Reaction time (hr.)	% Reaction	Light petroleum extract (mg.)	Ether extract (mg.)
1	0.505	10	0.235	-	150	7	77.2	36	246
2	0.543	5	5.511	10	150	7	46.7	329	193
3	1.047	5	4.721	15	135	4	60.4	92	946

In expt. 1, heating DIPG with vinyl chloride in the presence of powdered potassium hydroxide at the temperature (150°) and for the time (7 hr.) reported by Mikhant'ev and Lapenko (1957) resulted in 77% reaction but with little evidence of vinyl ether formation. The Russian workers employed dioxan as

a/...

a solvent in their preparation and the effect of this was examined using sufficient potassium hydroxide (+20% excess) to react with all the vinyl chloride (2). A dark red syrup was obtained on concentration of the dioxan filtrate. Extraction of this with light petroleum yielded an appreciable quantity of a syrup (329 mg.) but the product failed to distil in a high vacuum. Less drastic conditions (3) led to products that were mainly DIPG, indicating that little or no vinylation had occurred.

Preparation of 1, 2:5, 6-Di-O-isopropylidene-3-O-vinyl-α-D-glucofuranose by a Transvinylation Reaction.

The synthesis of DIPG vinyl ether was next attempted by the transetherification method of Watanabe and Conlon (1957), in which the alcohol to be vinylated reacts with an alkyl vinyl ether, e.g. isobutyl vinyl ether, in the presence of a mercuric salt of a weak acid, the most efficient being mercuric acetate. An equilibrium mixture results which can be represented by:-

$$R'OCH{=}CH_2 \quad + \quad ROH \quad \rightleftharpoons \quad R'OH \quad + \quad ROCH{=}CH_2$$

alkyl vinyl ether	alcohol to be vinylated	byproduct alcohol	required vinyl ether

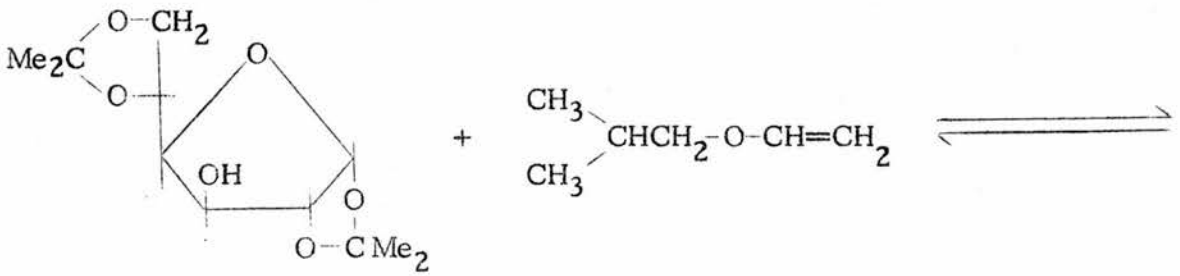
Two general methods are available for altering the position of the equilibrium to provide the required vinyl ether in optimum yield. In the first, it is directly fractionated out of the refluxing reaction mixture containing a high-boiling alkyl vinyl ether, the alcohol being vinylated and the byproduct alcohol./...

alcohol. This is feasible since vinyl ethers in general have lower boiling points than those of the alcohols from which they are derived. Good yields are obtained since the equilibrium alters continuously to form more of the vinyl ether being removed. It is, however, inapplicable in the present instance because the vinyl ether of DIPG has a much higher boiling point than any of the alkyl vinyl ethers normally used in this reaction.

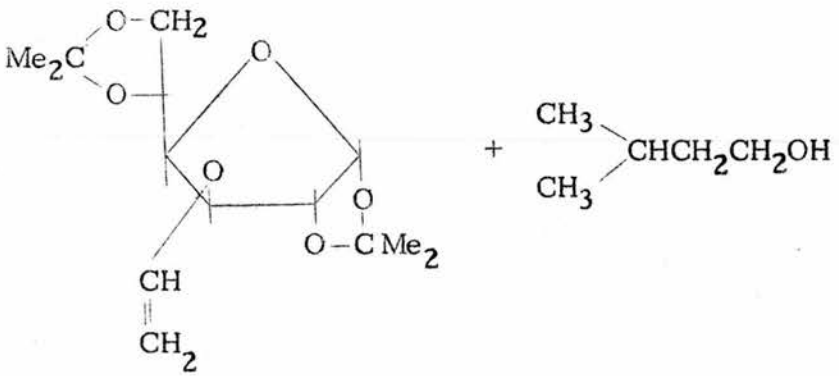
The second method was therefore adopted, namely, the utilisation of an excess of the alkyl vinyl ether, e.g. isobutyl vinyl ether, to drive the equilibrium in the preferred direction. The equilibrium is then arrested by inactivating the catalyst with potassium carbonate, after which the product is separated from the reaction mixture. The major disadvantage of the method lies in the relatively low yields obtained. Nevertheless, it offers milder reaction conditions than the high temperature, acetylene reaction of Mikhant'ev and Lapenko (1957), and consequently, less chance of degradation of the DIPG residues.

DIPG was refluxed for 6 hr. with pure mercuric acetate and an excess of isobutyl vinyl ether (b.p. 83-4°), when the following was considered to be the main reaction taking place:-

DIPG/...



DIPG isobutyl vinyl ether



DIPG vinyl ether isobutyl alcohol

Addition of potassium carbonate to the cooled reactants caused excess DIPG to crystallise out. After concentration, a syrup was obtained but attempts to isolate the vinyl ether by high vacuum distillation in the presence of barium carbonate failed due to decomposition above 120° (bath temperature). Both DIPG and mercury were found in the decomposition products, the latter indicating the presence of mercury compounds in the syrup. Mercurous carbonate decomposes around 130° and since it may have arisen from the double decomposition of mercuric acetate and potassium carbonate, the latter was omitted from the next reaction, rapid cooling only being used to arrest the equilibrium. The solution was then washed with 5% sodium hydroxide/...

hydroxide solution to remove as many of the side-products and reactants as possible, principally isobutyl alcohol, unreacted DIPG and mercuric acetate. Concentration and high vacuum distillation afforded in 5% yield a syrup which became semi-crystalline. Infrared analysis showed a strong (C=C) doublet at 1645, 1620 $cm.^{-1}$ characteristic of vinyl ethers (Davison and Bates, 1953) and a small OH absorption peak at 3480 $cm.^{-1}$, indicating a small amount of contaminating DIPG. Chromatography of the product by a new procedure designed specifically for the separation of isopropylidene sugar derivatives (Barnett and Kent, 1961) confirmed the presence of a small amount of DIPG in addition to the major component which was presumably the required vinyl ether. A third minor component was closely associated with the vinyl ether on the paper chromatogram; this was thought to be DIPG formed while the chromatogram was developing, since an aqueous medium was used (methanol:water - 6:4) and vinyl ethers are known to hydrolyse readily, even under neutral conditions, to form alcohols and acetaldehyde (Schildknecht et al., 1947):-

$$\underset{\text{vinyl ether}}{ROCH{=}CH_2} + \underset{\text{water}}{H_2O} \longrightarrow \underset{\text{Alcohol}}{ROH} + \underset{\text{acetaldehyde}}{CH_3.CHO}$$

The preparation was repeated using up to 50 g. DIPG with yields varying from 4-7%; all of the products slowly crystallised, whereupon an attempt was made to isolate the crystalline component by crystallisation from hexane solution. The crystals proved to be DIPG, however, and the syrup recovered from the mother liquor was redistilled to yield the vinyl ether as a colourless oil/...

oil which showed no tendency to crystallise. Infrared analysis revealed a reduction in the OH absorption peak at 3490 $cm.^{-1}$ and the refractive index was lower.

Difficulty was experienced in repeating this preparation because decomposition invariably occurred to a greater or less extent during distillation, with the formation of DIPG and a yellow gum containing mercury compounds and free mercury. Examination of the mechanism of the reaction, according to Watanabe and Conlon, suggested that various mercury acetals were involved, which in all probability were not being extracted completely and were decomposing during the high vacuum distillation:-

$$Hg(OAc)_2 \rightleftharpoons HgOAc^{\oplus} + AcO^{\ominus}$$

$$HgOAc^{\oplus} + ROCH{=}CH_2 + R'OH \rightleftharpoons \underset{R'O}{\overset{RO}{\diagdown\!\diagup}}CHCH_2HgOAc + H^{\oplus}$$

isobutylvinyl ether DIPG acetoxymercuri-acetal

$$\underset{R'O}{\overset{RO}{\diagdown\!\diagup}}CHCH_2HgOAc + ROCH{=}CH_2 + R'OH \rightleftharpoons \left[\underset{R'O}{\overset{RO}{\diagdown\!\diagup}}CHCH_2\right]_2Hg + HOAc$$

A B C mercury diacetal D

$$\underset{R'O}{\overset{RO}{\diagdown\!\diagup}}CHCH_2HgOAc + R'OCH{=}CH_2 + ROH$$

DIPG vinyl ether E; isobutyl alcohol F

Cf/...

Of the six compounds present in the equilibrium reaction mixture, DIPG (C), isobutyl vinyl ether (B) and isobutyl alcohol (F) would be removed almost completely by crystallisation (C), by washing with sodium hydroxide solution (C and F) and by concentration (B), leaving the sugar vinyl ether (E) and the mercury acetals (A and D) in the final syrup which was subjected to high vacuum distillation.

An unsuccessful attempt was made to overcome this problem by inactivating the catalyst after the reaction with potassium carbonate, after Watanabe and Conlon, and washing the solution with concentrated ammonia solution to complex and dissolve mercury compounds. However, mercury compounds and DIPG still contaminated the final distillate.

Treatment of the sodium hydroxide-washed reaction solution with metallic sodium, which is known to decompose mercury alkyls in the cold (Rochow et al., 1957) was then tried. Firstly, ultrasonically dispersed sodium (Pratt and Helsby, 1959) in light petroleum at 20° was used to decompose the mercury acetals under nitrogen; a dark-coloured residue containing sodium amalgam quickly deposited, showing that decomposition of some organomercury compounds had occurred. The supernatant solution was worked up to give DIPG vinyl ether in 15% yield, which was an improvement on all previous preparations. Most of the unreacted DIPG was recovered from the sodium hydroxide washings by extraction with chloroform, bringing the overall yield of the ether up to 50%. Treatment with sodium wire at 20° proved to be slightly/...

slightly more effective, improving the yield of the vinyl ether after one distillation up to 22%, or 76% allowing for recovered DIPG. It was found necessary, however, to leave the sodium wire in the solution at least 17 hr. at 20°, or preferably to heat at 70-80° for 45 min., to complete the reaction.

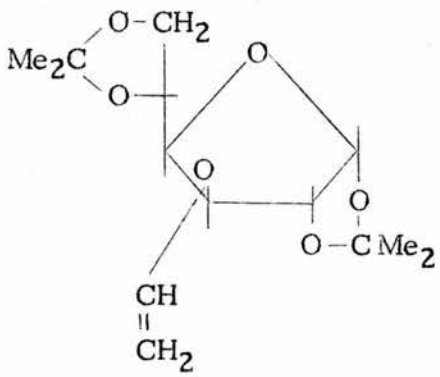
The material after one high vacuum distillation was still not completely pure as infrared examination still showed a small OH absorption. Final purification, consisting of triple high vacuum distillation over sodium wire, was found to remove this hydroxyl contamination completely and also to remove trace amounts of mercury compounds that had survived the initial sodium treatment. Distillation on a 10 g. scale from potassium led to a product with a sharp acetylenic smell and with additional small absorption peaks in the infrared spectrum, indicating contamination. Evidently, potassium is too reactive and causes some degradation.

The preparative procedure was further improved by treating the washed and carefully dried reaction solution directly with sodium wire, instead of first evaporating off the excess isobutyl vinyl ether and adding light petroleum before sodium wire treatment.

In the final standard preparation, DIPG, isobutyl vinyl ether and pure mercuric acetate catalyst were refluxed together for 6 hr., the solution cooled rapidly to arrest the equilibrium and washed with 5% sodium hydroxide solution. Treatment with sodium wire then decomposed the mercury acetals present, most of the decomposition products being subsequently removed by further/...

further washing with 5% sodium hydroxide solution. Concentration and high vacuum distillation gave crude DIPG vinyl ether in 20-8% yield; overall yield after DIPG recovery remained at 50-75%.

Final purification consisted of triple high vacuum distillation (b.p. 68°/0.008 mm.) from sodium wire. The colourless oil isolated by this procedure analysed correctly as 1,2:5,6-di-O-isopropylidene-3-O-vinyl-α-D-glucofuranose (XV):-



(XV)

Its rotation ($[\alpha]_D$ -24° in ethanol) was similar to these of the other DIPG unsaturated derivatives described previously. The refractive index (n_D^{20} 1.459) was markedly different from that reported by Mikhant'ev and Lapenko (n_D^{20} 1.468). The monomer was chromatographically pure when subjected to the special chromatographic procedure referred to before, indicating that the minor component previously found closely associated with the vinyl ether was indeed an impurity, probably a mercury acetal.

Cationic Polymerisation of Alkyl Vinyl Ethers

Vinyl ethers are relatively specific in their catalyst requirements for polymerisation/...

for polymerisation. They cannot be polymerised by free radical catalysts but are rapidly polymerised by Lewis acids, such as boron trifluoride and stannic chloride, or by cation-forming substances such as iodine and silver perchlorate (Pepper, 1954). These polymerisations are best conducted at low temperatures (<-60°) both to control the reaction, which can go violently, and to eliminate undesirable side reactions. Schildknecht et al. (1948) showed that the heterogeneous polymerisation of isobutyl vinyl ether in a hydrocarbon medium at -70° with boron trifluoride etherate (BTFE) formed a crystalline stereoregular polymer which gave a typical X-ray fibre diagram; this was the first example of a stereospecific polymerisation (Bawn, 1962). The reaction is heterogeneous for the polymer grows on the surface of the frozen BTFE catalyst particles. In a later paper (Schildknecht et al., 1949) this "heterophase", "polyphase" or "proliferous" polymerisation was further discussed and the claim was made that it was unique in giving an exceptionally high degree of chain regularity and crystallinity. Polymers of similarly high D.P. but not of such regular structure were claimed to result from "flash" polymerisation of isobutyl vinyl ether, in which solutions of boron trifluoride and the ether in liquid propane at -70° were rapidly mixed, causing the immediate formation of rubber-like polymers in high yield. In contrast, bulk polymerisation resulted in low-molecular weight material since the reaction occurred in the liquid monomer phase and the polymer usually remained dissolved. Solution polymerisation gave slightly better results, partly

through/...

through improved temperature control of the reaction in the presence of the diluent. Above 0°, however, solid polymer was only obtained by using monomer of especially high purity and by adding catalyst gradually in dilute solution, e.g. 1% BTFE in ether, until polymerisation occurred.

The mechanism of cationic polymerisations such as those described is complex and little understood. A simple carbonium-ion propagation can be formulated for vinyl ether polymerisations with catalysts such as BTFE, which dissociates to form the active catalyst:-

Initiation:

$$BF_3.OEt_2 \rightleftharpoons [BF_3.OEt]^{\ominus}\ Et^{\oplus}$$

boron trifluoride etherate

Propagation:

$$[BF_3.OEt]^{\ominus}\ Et^{\oplus} + CH_2{=}\underset{\underset{OR}{|}}{CH} \longrightarrow Et{-}CH_2{-}\overset{\oplus}{\underset{\underset{OR}{|}}{CH}}\ [BF_3.OEt]^{\ominus}$$

alkyl vinyl ether — carbonium ion

$$\longrightarrow Et\left[CH_2{-}\underset{\underset{OR}{|}}{CH}\right]_n{-}CH_2{-}\overset{\oplus}{\underset{\underset{OR}{|}}{CH}}\ [BF_3.OEt]^{\ominus}\ \text{etc.}$$

Kennedy (1959) has recently shown, however, that very few chains originated from ethyl groups; he considers that the general mechanism proposed above may be operative but that a chain transfer step also occurs.

As a first step towards the cationic polymerisation of DIPG vinyl ether, isobutyl vinyl ether was polymerised in typical "heterophase" fashion, following the more detailed description given by Sorenson and Campbell (1961) of Schildknecht's/...

Schildknecht's method (1948). Purified isobutyl vinyl ether, dissolved in liquid propane which had been dried by condensing over sodium hydroxide and afterwards redistilled, was treated with a few drops of BTFE catalyst at -78° to promote polymerisation. The tough, yellow rubber, isolated in 86% yield by precipitation from benzene solution into methanol, had an inherent viscosity of 0.48 in toluene, whereas Sorenson and Campbell claimed a 57-60% yield of white solid with an inherent viscosity of about 1.5.

Efforts were made to improve this relatively low viscosity. Systematic purification of each of the reactants revealed that commercial propane was very impure, propylene being a major contaminant. Because of this, the gas was subsequently passed through gas washers containing sulphuric acid and then through a column of sodium hydroxide pellets before being condensed directly into the reaction vessel. Schildknecht et al. (1948) referred to precautions being taken to avoid localised rapid reaction and rise in temperature at the point of entry of the catalyst into the propane solution, by the introduction of solid carbon dioxide into the reaction vessel. Consequently, in the next reaction, each drop of catalyst was injected into a freshly broken piece of solid carbon dioxide, which was then dropped into the reaction mixture. In this case a pale yellow rubber was isolated in 76% yield with an inherent viscosity of 1.66.

Cationic/...

Cationic Polymerisation of 1,2:5,6-Di-O-isopropylidene-3-O-vinyl-α-D-gluco-furanose (XV)

Reference will be made throughout this discussion to the particular sample of DIPG vinyl ether described in the Experimental. This is necessary because the developments of monomer preparation and polymerisation were closely linked. Isobutyl vinyl ether was used as a standard monomer for comparing the effects of different conditions of polymerisation.

The first sample of DIPG vinyl ether prepared (A, p. 55) was polymerised in 14 parts liquid propane, in which it dissolved with great difficulty, using BTFE catalyst at -78° as described for isobutyl vinyl ether. Polymer was isolated as a white powder in poor yield (11%) and with a low viscosity (0.11).

In an effort to improve solubility, monomer B (p. 55) was treated with BTFE in propane:hexane:methylene dichloride (10:5:5 by volume) solution, but polymerisation in this medium failed. This lack of success was attributed in part to impurities in the commercial propane, and because of the difficulty of obtaining pure propane this solvent was not used again. Monomer B, nevertheless, failed to produce polymer in hexane:methylene dichloride (8:2) solution, which led to a study of the effect of concentration of monomer in the polymerisation solution.

A series of experiments was then conducted with isobutyl vinyl ether to investigate this. At -60°, polymerisation occurred rapidly on the addition of 1 drop of BTFE catalyst to a 25% solution of isobutyl vinyl ether in hexane but/...

but was considerably delayed in a 10% solution. Quantitatively, a 25% solution gave a 97% yield of polymer with a viscosity of 0.96, whereas a 10% solution polymerised for a longer time gave 83% conversion and a viscosity of 0.64. The experiment was not repeated with the sugar monomer, for a 25% solution of sample B in hexane solidified at -60°. Methylene dichloride, however, was found to be an excellent solvent for the vinyl ether, forming solutions which remained liquid at low temperatures. A series of polymerisations was carried out with monomer B in this solvent, using different conditions and catalysts, details of which are recorded below:-

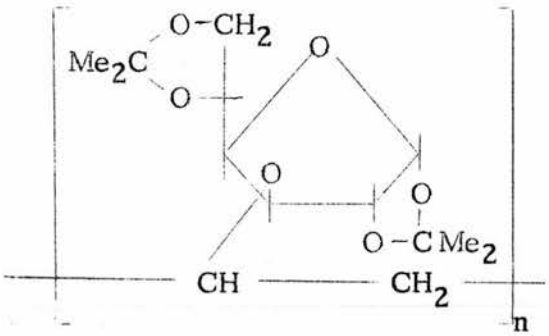
Table 10

Cationic polymerisation of DIPG vinyl ether in methylene dichloride solution

Expt. No.	Monomer/ solvent ratio (w/v)	Catalyst	Temp. (°C)	Time (hr.)	$[\eta]$	$[\alpha]_D$	% Conversion
1	1/2	BTFE (70 mg.)	-66	4.5	0.14	+5°	77.9
2	1/2	BTFE (70 mg.)	-20	4.5	0.06	+3	71.9
3	1/4	BTFE (70 mg.)	-78	4.5	0.08	+6	74.6
4	1/4	BTFE (10 mg.)	-78	5	-	-	-
5	1/4	$SnCl_4$ (67 mg.)	-78	5	0.11	+10	85.8
6	1/4	$AlCl_3$ (12 mg.)	-78	5	-	-	3.5
7	1/4	$AgClO_4$ (81 mg.)	-78	5	-	-	-
8	1/4	BTFE (70 mg.)	-78	4.5	0.08	+5	75.9

In/...

In the first experiment polymer was obtained in satisfactory yield (78%) but the viscosity was still low. The polymer, however, analysed satisfactorily as poly(1,2:5,6-di-O-isopropylidene-3-O-vinyl-α-D-glucofuranose) (XVI)



(XVI)

When this was repeated at -20° (2), the viscosity of the product was even lower. Reducing the concentration of monomer from 1 in 2 to 1 in 4 again gave a product in good yield but with a low viscosity (3). When only 10 mg. of catalyst was used (4), no polymer was formed.

It is significant that the small, positive optical rotation (+3° → +6°; tetrachloroethane) of the polymers differed radically from that of the monomer ($[\alpha]_D$ - 23°). The possibility of loss of some isopropylidene groups could not be excluded, for although boron trifluoride is the most active cationic catalyst (Pepper, 1954), it may be degradative to carbohydrate monomers containing a high concentration of oxygen atoms. Both boron trichloride and tribromide have been found to deacylate and demethylate carbohydrate derivatives at room temperature and, in particular, to remove both isopropylidene groups from DIPG (Bonner, Bourne and McNally, 1960). Bonner and Saville (1960) have/...

have also shown that boron trichloride is an efficient reagent for opening cyclic acetal rings, apparently through coordination with the acetal oxygen atom. From this point of view, other catalysts were investigated in an effort to increase the viscosity (Table 10, above). With stannic chloride (5), polymer was isolated with a similar viscosity to that obtained with BTFE but the rotation was higher (+10°) than before. A very low yield resulted when aluminium chloride in saturated carbon tetrachloride solution was used as catalyst (6) and no polymer was precipitated with silver perchlorate in ether solution as catalyst (7). This has been shown to give low-molecular weights, compared to stannic chloride, in the polymerisation of octyl vinyl ether at 25° (Eley and Richards, 1949). The results showed that BTFE and stannic chloride were the most efficient catalysts.

In an effort to increase viscosity, the purity of the methylene dichloride solvent was next examined after it had been noted that it became opaque when cooled to low temperature (<-50°) and eventually formed a slight precipitate. However, polymerisation in a highly purified sample (8) did not improve the viscosity.

The composition of the polymerisation medium was also studied to establish what advantage "heterophase" polymerisation had over homogeneous polymerisation in solution, as claimed by Schildknecht et al. (1949). Isobutyl vinyl ether polymerised in methylene dichloride solution with BTFE to form a tacky syrup in 85% yield with a viscosity of only 0.28; reaction in

a/...

a mixture of hexane and methylene dichloride (3:1 by volume) afforded a white, non-tacky rubber in 98.5% yield with a viscosity of 1.0. Clearly, the latter system showed that "heterophase" polymerisation was a much more efficient process in building up high-molecular weight polymer: the formation of polymer as a separate phase around the frozen catalyst particles was observed during the reaction.

Heterophase polymerisation was then applied to the sugar monomer, using product B (p. 55):-

Table 11

Heterophase polymerisation of DIPG vinyl ether in hexane:methylene dichloride (3:1 by vol.)

Expt. No.	Monomer (250 mg.)	Solvent (ml.)	Catalyst (mg.)	Yield (%)	$[\eta]$	$[\alpha]_D^{20}$
1	Product B, redistilled	1.0	BTFE (40)	71.1	0.12	+3°
2	Redistilled from sodium	1.0	BTFE (40)	83.0	0.16	+3
3	Redistilled from sodium	1.0	$SnCl_3$ (30)	74.8	0.16	+8
4	Redistilled from potassium	1.0	BTFE (40)	88.1	0.16	+5
5	Redistilled from potassium	1.0	$SnCl_4$ (30)	72.2	0.21	+13
6	Redistilled from potassium	0.5	BTFE (40)	86.9	0.13	+3
7	Redistilled from potassium	1.0	BTFE (6.5)	81.9	0.21	+4

The results showed that heterophase polymerisation in itself failed to produce a high viscosity polymer from purified monomer B, although the same conditions gave a high viscosity polymer from isobutyl vinyl ether. This suggested/...

suggested that the purity of the DIPG vinyl ether was the limiting factor, and further purification of the monomer as described on p. 55 was undertaken. A single distillation of monomer B from sodium or potassium gave a slight increase in viscosity from 0.12 to 0.16 with both BTFE and stannic chloride (expts. 2-4). In expt. 4, no opacity developed on cooling the solution to -78° and it was noted that polymer did not form until the second drop (1 drop ≡ 10 mg.) of catalyst had been added. This was in agreement with Schildknecht et al. (1949) who reported that polymerisation did not occur until a critical catalyst concentration was reached. A viscosity >0.2 was first obtained in expt. 5, but decreasing the volume of hexane:methylene dichloride caused a significant drop in viscosity (6). In (7), 6.5 mg. of BTFE were sufficient to promote polymerisation. Again polymers produced by stannic chloride catalysis had a higher rotation (+8°→ +13°) than those from BTFE (+3°→ +5°).

Large-scale Preparations of Poly(1,2:5,6-di-O-isopropylidene-3-O-vinyl-α-D-glucofuranose (XVI)

It was found satisfactory to purify the vinyl ether by redistilling it three times from sodium wire, the last time directly into the polymerisation vessel. This purified material (C, p. 58) was then subjected to "heterophase" polymerisation in hexane:methylene chloride (3:1 by volume) with BTFE catalyst added cautiously until sufficient was present to promote polymerisation. A large, rubbery mass of insoluble polymer soon built up and was isolated as a white powder in 77% yield. Its rotation ($[\alpha]_D$ +2°) was consistent with/...

with that of other polymers prepared with BTFE, but its viscosity (0.65) was markedly higher. The explanation for this probably lies in the high purity of the monomer but the addition of the minimum quantity of catalyst may also be an important factor. This result showed clearly that there was no defect inherent in the monomer structure preventing high-molecular weight polymer from being formed. At one time it had been thought that the large number of oxygen atoms in the sugar vinyl ether might be complexing with BTFE and so preventing polymerisation.

The polymer proved to be soluble in chloroform and tetrachloroethane but insoluble in other common organic solvents. Its infrared spectrum (Appendix III) showed a strong resemblance to that of the pure monomer but the strong vinyl doublet at 1645, 1620 $cm.^{-1}$ was absent.

In a later preparation, the rubbery mass typical of high-molecular weight polymer jammed the stirrer and prevented efficient trituration in the ammoniacal methanol solution, which normally broke down the solid mass into a white powder. On approaching room temperature, the product turned yellow due to the degradative action of traces of occluded catalyst. When an attempt was made to dissolve the polymer for reprecipitation, a large amount of insoluble gel remained, presumably having originated from degradative cross-linking caused by the catalyst at the higher temperature. To prevent this, the polymer mass was subsequently dissolved in situ by the addition of chloroform, cooled to -60°, containing pyridine to neutralise excess catalyst.

This/...

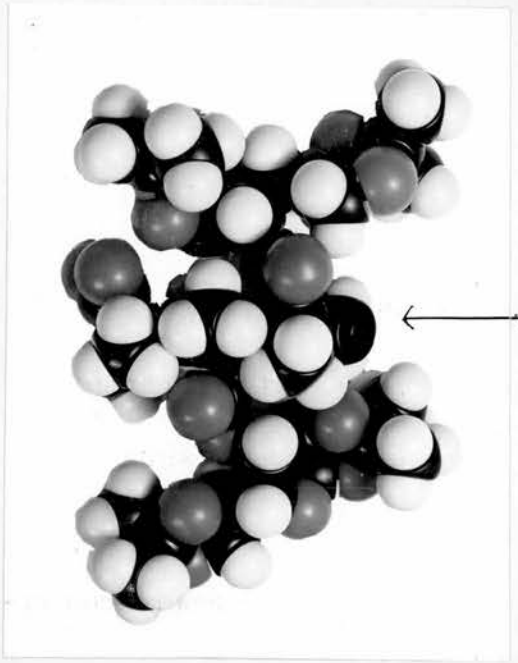
This was followed by precipitation in methanol and working-up in the normal manner.

At the conclusion of this work a paper was published by Whistler et al. (1962) on the preparation and polymerisation of 1,2:3,4-di-O-isopropylidene-6-O-vinyl-D-galactopyranose which must be compared with that of 1,2:5,6-di-O-isopropylidene-3-O-vinyl-α-D-glucofuranose, described above. Vinylation was achieved by reaction with acetylene at atmospheric pressure and high temperature (160-80°) in the presence of potassium hydroxide. The monomer was found to polymerise with standard cationic initiators at room temperature in 3.5% methanolic solution, but yields and viscosities were not reported.

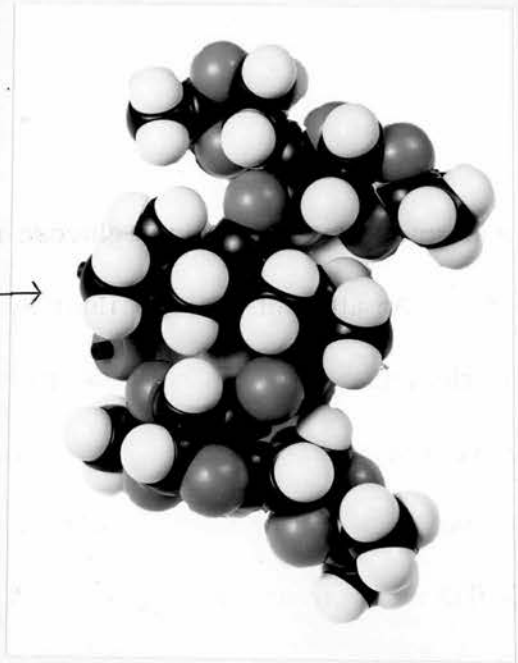
Attempted Preparation of Poly(3-O-vinyl-D-glucopyranose)

The conditions successfully employed for the deacetonation of poly(1,2:5,6-di-O-isopropylidene-3-O-methacryloyl-D-glucofuranose) were applied to the poly(DIPG vinyl ether) but only a small portion of syrup was obtained from the hydrolysate after treatment with N hydrochloric acid at 100°. From its failure to precipitate in ethanol, the product appeared to be non-polymeric.

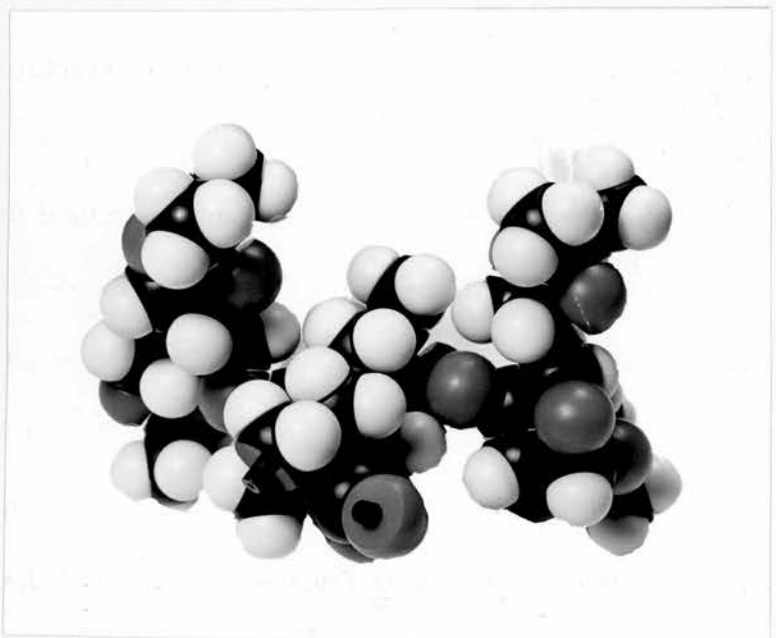
Chromatographic examination of the hydrolysate in a similar experiment showed only glucose to be present and, on this basis, the optical rotation of the hydrolysate was found to correspond exactly to the calculated weight of glucose that would have resulted from the portion of polymer solubilised. The insoluble residue resembled the original polymer and further acid treatment confirmed/...



Poly(DIPG methacrylate) showing two DIPG residues attached to the main chain, which has its $-CH_3$ groups uppermost.



Poly(DIPG vinyl ether) showing two DIPG residues attached to the main chain, which has its $\geq CH_2$ groups uppermost.



Another configuration of the poly(DIPG methacrylate) molecule with the DIPG residues lying at right angles to the main chain, showing more clearly the better spacing and greater flexibility of the structure.

confirmed that it contained glucose residues.

An attempt to find milder hydrolysis conditions showed that 50% acetic acid caused the same degradation of the polymer. No further attempts were made since the failure to undergo deacetonation without decomposition is clearly inherent in the structure of the polymer: a Catalin model of poly-(DIPG vinyl ether) shows that the carbon-carbon main chain and the isopropylidene-glucofuranose residueslie very close to each other due to the short ether connecting link. It seems possible that deacetonation may so disturb the polymer molecule that the ether link is broken and glucose is liberated. In contrast, in the poly(DIPG methacrylate) polymer, the main chain is separated from the isopropylideneglucofuranose residues by an ester linkage, which has an extra carbon atom, thus providing greater flexibility in the polymer structure. These points are illustrated opposite.

The failure of poly(DIPG vinyl ether) to deacetonate prevented the preparation of derivatives comparable to those prepared from the deacetonated methacrylate polymer. Nevertheless, it is believed that Watanabe and Conlon's transvinylation technique has been sufficiently adapted to make it generally applicable for the preparation of vinyl ethers from other suitably substituted sugars. Both 2,3:4,5-di-O-isopropylidene-D-fructose and 1,2:3,4-di-O-isopropylidene-D-galactose, for example, have primary alcohol groups (at C(1) and C(6) respectively) available for vinylation. Although the vinyl ethers and their polymerisations have been reported by other methods (Reppe et al., 1956; Whistler/...

Whistler et al., 1962), the attempted deacetonation of their high-molecular weight polymers would make an interesting comparison with the experiments described above.

SUMMARY AND CONCLUSIONS

1. In the Introduction the possible advantages of introducing hydrophilic groups such as glucose residues into synthetic addition polymers were discussed. The main objects of this investigation were to demonstrate that such polymers could be formed and to study some of their chemical and physical properties. The scope of the investigation was limited to the introduction, and subsequent polymerisation, of various vinyl groups into DIPG(1,2:5,6-di-O-isopropylidene-α-D-glucofuranose) which could be subsequently deacetonated in the polymers to expose free sugar units. It was expected that the deacetonated polymer would be similar to natural polysaccharides in some respects, such as in the reactions of its free hydroxyl groups, and dissimilar in others through the presence of reducing groups at C(1) and of the polycarbon main chain.

2. A literature survey showed that there is a growing interest in such carbohydrate-derived polymers. Earlier work was concerned with making insoluble, cross-linked structures but soluble, linear polymers are currently being sought. Several monofunctional carbohydrate monomers have been synthesised, but few as yet have been polymerised.

3. The 3-O-methacryloyl ester of DIPG was prepared in 50-70% yield by treating DIPG with methacrylic anhydride in pyridine. The various stages of purification, including final high vacuum distillation in the presence of tetrachlorohydroquinone/...

tetrachlorohydroquinone inhibitor, were checked by infrared spectroscopy and by the ability of the monomer to polymerise to a high-molecular weight. The viscous syrup slowly crystallised m.p. 34-5°.

4. Pure monomer was polymerised in 1:1 (w/v) benzene solution with free radical catalysts, such as azobisisobutyronitrile at 70°, to give a relatively high-molecular weight linear polymer in 76% yield with an inherent viscosity of 0,5. The product was soluble in benzene, chloroform and acetone, and had a specific rotation in tetrachloroethane (-49°) considerably more negative than that of the monomer (-32°).

5. Deacetonation of the polymer was readily achieved with N hydrochloric acid at 100°. The stable, water-soluble poly(3-O-methacryloyl-D-glucose), isolated in 74% yield, proved that it was possible to synthesise the structures envisaged in the Introduction. The specific rotation in water was positive (+ 50°) and indicative of the free glucopyranose residues exposed; its aqueous solution was strongly reducing to Fehling's solution and hypoiodite, indicating that the reducing group was free.

6. The deacetonated polymer underwent standard carbohydrate reactions such as acetylation, methylation and carbanilation, although it was not always possible to substitute completely all four free hydroxyl groups. Reactions of the free reducing group at C(1) were examined in detail, e.g. by oxidation with chlorous acid, by reduction with sodium borohydride and in the formation of a phenylhydrazone and diphenylformazan. The polyacid, poly(3-O-methacryloyl-D-gluconic acid),/...

methacryloyl-D-gluconic acid), produced by oxidation, showed some similarity to naturally-occurring polyuronic acids by forming both soluble and insoluble salts with metallic ions.

7. The 3-O-allyl ether of DIPG was prepared as a colourless oil in high yield (94%) by a simple reaction involving heating DIPG with allyl bromide in dioxan solution in the presence of powdered sodium hydroxide. The monomer was deacetonated with 0.5 N sulphuric acid and 3-O-allyl-D-glucose was isolated as a crystalline compound: periodate oxidation of its methyl glucopyranoside confirmed its structure.

8. The pure allyl ether failed to polymerise to an appreciable extent either in 1:1 (w/v) benzene solution or in the absence of solvent with benzoyl peroxide catalyst at 80°. Reasons for this result were suggested from a general discussion of allyl polymerisation.

9. Attempted preparation of the 3-O-vinyl ether of DIPG by reacting vinyl halides with the sodium or potassium salts of DIPG failed and the same result was obtained using DIPG instead of its salts and vinyl chloride and powdered potassium hydroxide to produce acetylene in situ. Vinylation was achieved by a transvinylation method which involved the separation of DIPG vinyl ether from an equilibrium mixture resulting from heating together DIPG, isobutyl vinyl ether and mercuric acetate catalyst. Crude monomer was eventually obtained in 28% yield and most of the unreacted DIPG was recoverable, bringing/...

bringing the overall yield to 50-70%.

10. Treatment of the reaction product with sodium decomposed mercury acetals formed in the vinylation reaction and triple high vacuum distillation over sodium wire enabled pure monomer to be isolated as a colourless oil, free from mercury and hydroxyl contamination. Purity of each monomer sample was judged mainly from its infrared spectrum and refractive index, and from the inherent viscosity and yield of polymer formed from it.

11. Conditions for cationic polymerisation were established using isobutyl vinyl ether as a standard. Homogeneous polymerisation in methylene dichloride solution at -78° was found to give low viscosity products, whereas "heterophase" polymerisation, with the polymer growing as a separate phase on frozen catalyst particles, gave appreciably higher viscosities, in agreement with the fundamental studies of Schildknecht. A "heterophase" polymerisation medium of hexane:methylene dichloride (3:1 v/v) at -78° was suitable for both isobutyl vinyl ether and the sugar monomer.

12. Boron trifluoride etherate and stannic chloride were both effective catalysts for polymerising DIPG vinyl ether, giving polymers of low positive rotations; stannic chloride gave polymers with a slightly higher rotation. Other cationic catalysts, such as silver perchlorate and aluminium chloride, were ineffective.

13. Highly purified monomer was polymerised at -78° in hexane:methylene dichloride (3:1) with the minimum amount of boron trifluoride etherate catalyst

to/...

to form high-molecular weight polymer in 77% yield with an inherent viscosity of 0.65 and a specific rotation of +2° (in tetrachloroethane). It was soluble in chloroform and tetrachloroethane.

14. Attempted deacetonation of the poly(vinyl ether) in the manner described for the methacrylate polymer (N hydrochloric acid at 100°) caused breakdown of the polymer structure with the liberation of free glucose. Milder reaction conditions using 50% (v/v) acetic acid also failed to give poly(3-O-vinyl-D-glucose). A possible explanation for this lies in the closely-packed, inflexible structure of the poly(DIPG vinyl ether).

15. In conclusion, the concept of introducing hydrophilic properties into a synthetic polymer by the incorporation of sugar residues has been established in the preparation of poly(3-O-methacryloyl-D-glucose). It is possible, however, that any industrial application of these monomers may lie in copolymerisation with suitably reactive, cheap monomers. In this respect, Kimura and Imoto (1961) have already shown that acrylonitrile and DIPG methacrylate form a copolymer which can be readily dyed by water-soluble dyestuffs after deacetonation.

16. The three DIPG monomers described show the range of possibilities arising from the introduction of vinyl groups, in that the allyl ether gives no polymer of significant molecular weight, the vinyl ether and methacrylate ester both give high polymers, but only the methacrylate leads to a product which can be readily deacetonated. Further work on other synthetic carbohydrate polymers might be rewarding.

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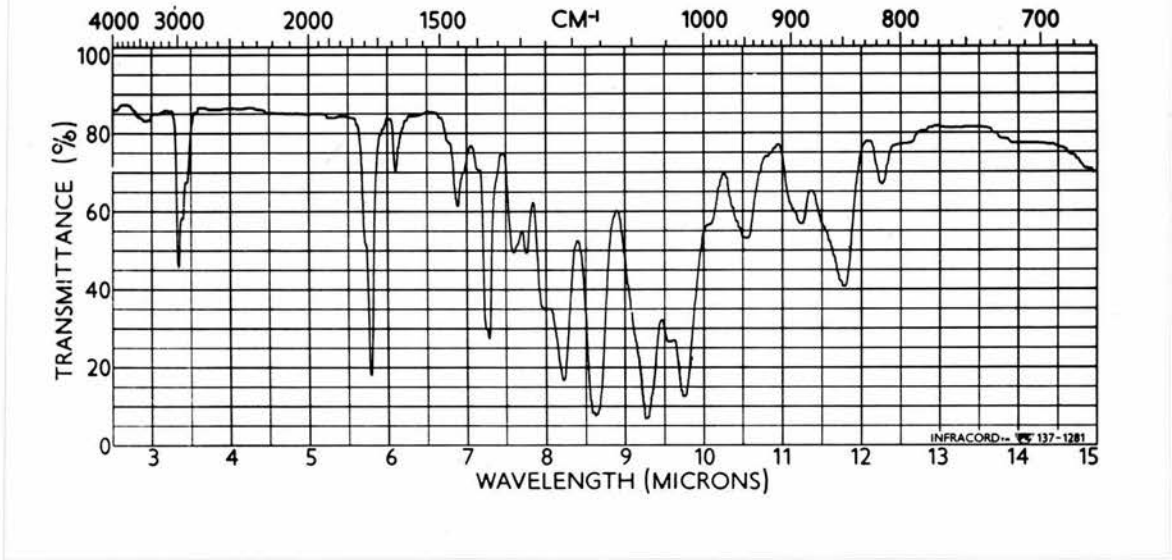
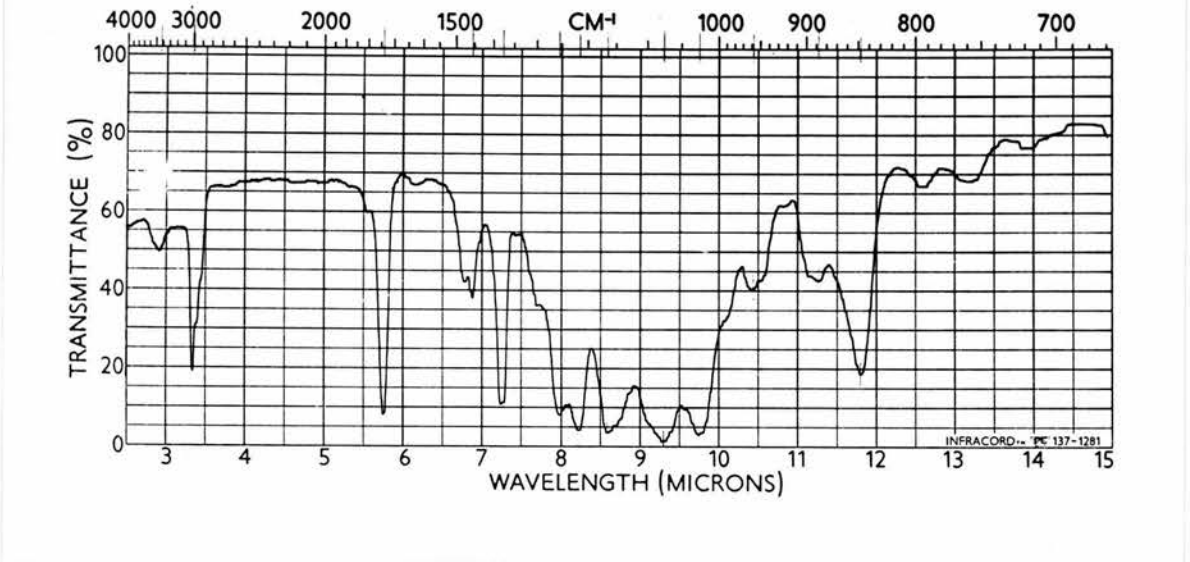
APPENDIX I

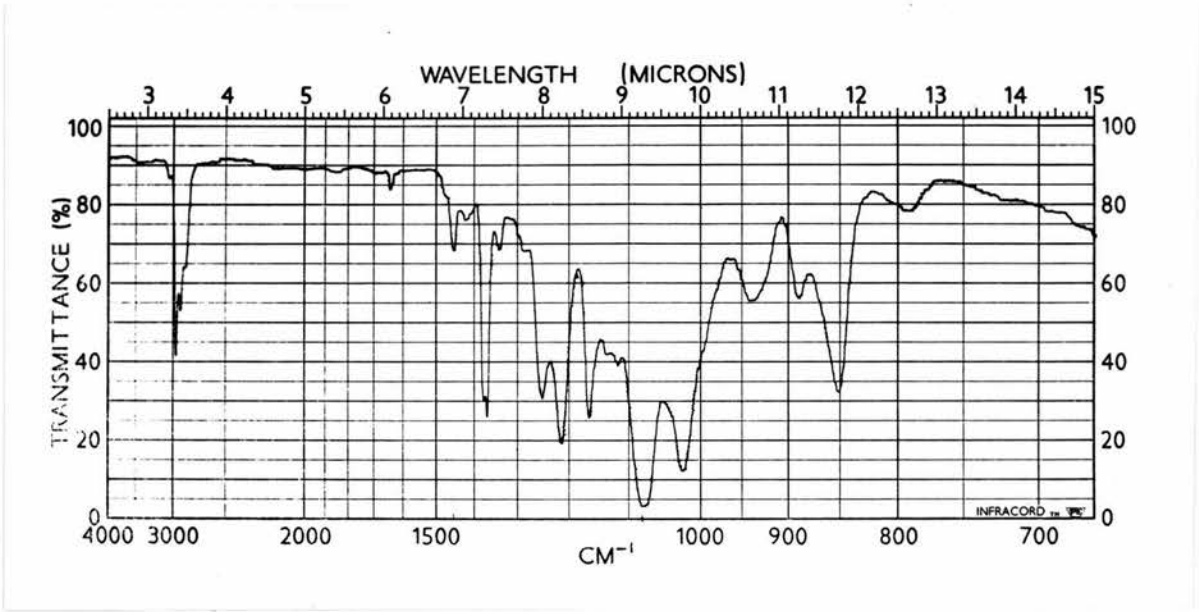


1, 2:5, 6-di-O-isopropylidene-3-O-methacryloyl-α-D-glucofuranose (II)
(film between sodium chloride plates)



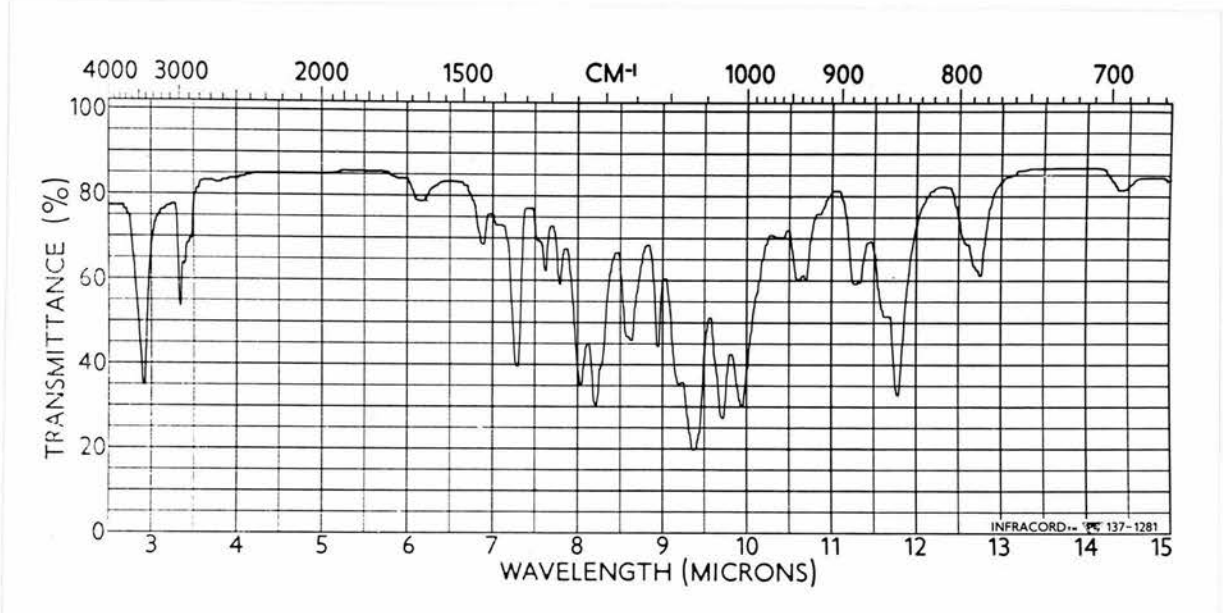
poly(1, 2:5, 6-di-O-isopropylidene-3-O-methacryloyl-α-D-glucofuranose) (III)
(in potassium bromide disc)

APPENDIX II



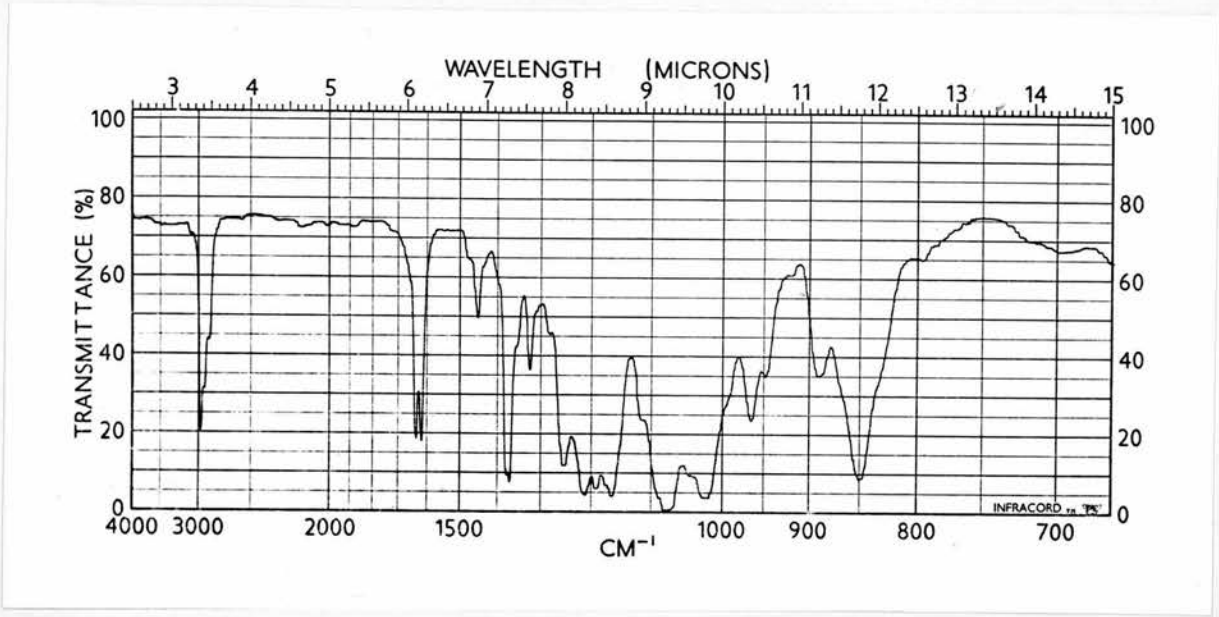
3-O-allyl-1, 2:5, 6-di-O-isopropylidene-α-D-glucofuranose (XIII)

(film between sodium chloride plates)



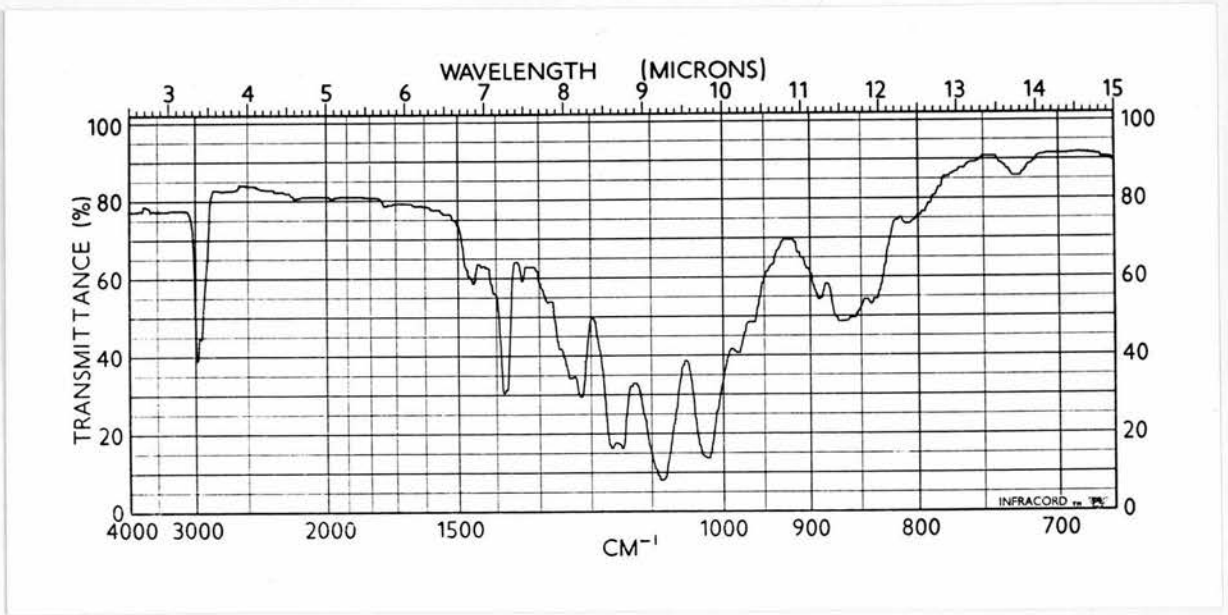
1, 2:5, 6-di-O-isopropylidene-α-D-glucofuranose (I)

(in potassium bromide disc)



1, 2:5, 6-di-O-isopropylidene-3-O-vinyl-α-D-glucofuranose (XV)

(film between sodium chloride plates)



poly(1, 2:5, 6-di-O-isopropylidene-3-O-vinyl-α-D-glucofuranose) (XVI)

(in potassium bromide disc)

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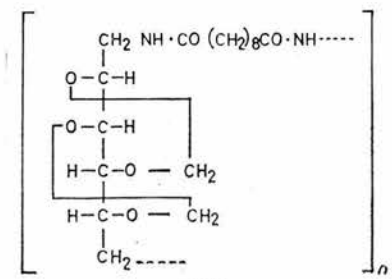
OPTICALLY ACTIVE POLYAMIDES AND POLYMETHACRYLATES CONTAINING SUGAR RESIDUES

By T. P. Bird, W. A. P. Black, E. T. Dewar and D. Rutherford

Arthur D. Little Research Institute, Inveresk, Musselburgh, Midlothian.

Previous attempts[1–3] to prepare synthetic fibres of the nylon-type from 1,6-diamino-1,6-dideoxy-2,4: 3,5-di-*O*-methylene-D-mannitol and dibasic acids were unsuccessful owing to the high temperatures necessary (>200°C.) in the melt polymerisation process. More recently, Wolfrom *et al.*[4] have succeeded in preparing short-chain nitrogen-containing polymers from 1,2:5,6-dianhydro-3,4-*O*-isopropylidene-D-mannitol and piperazine, ethanolamine, etc. and the products were soluble in organic solvents. Hydroxy-polyamides have been obtained[5] by reaction of tetra-*O*-galactaroyl dichloride with ethylenediamine and piperazine, but the acetylated polymers were insoluble in organic liquids and decomposed above 250° with no evidence of melting. Diamines have also been condensed at high temperatures with acetals and ketals of galactaric acid to give linear polyamides.[6]

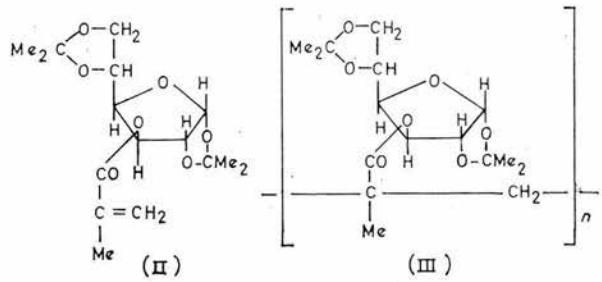
The new technique of interfacial polycondensation[7–9] is well suited to carbohydrate intermediates because of the low temperatures required for polymerisation, and we wish to report the preparation of poly(1-sebacamido-1,6-dideoxy-2,4 : 3,5-di-*O*-methylene-D-mannitol) (I) from 1,6-diamino-1,6-dideoxy-2,4: 3,5-di-*O*-methylene-D-mannitol[2] and sebacoyl dichloride (in carbon tetrachloride) using the stirred interfacial technique.[9]



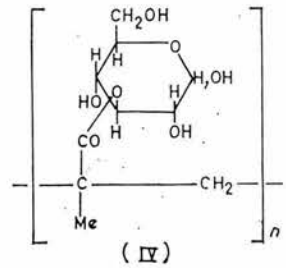
(I)

The material (I) melted at 150–160° and was dextrorotatory ($[\alpha]_D$+107° in pyridine). It was insoluble in water and common organic liquids but soluble in pyridine, dimethylformamide, dimethylsulphoxide and *m*-cresol. The intrinsic viscosity, $([\eta]_c=(1/c)\ln \eta_{soln.}/\eta_{solv.})$, of a solution of the polymer in pyridine (*c.*, 0·5 g./100 ml.; 25°) varied from 0·21 to 0·44 dl./g. 1,6-Diamino-1,6-dideoxy-2,4 : 3,5-di-*O*-methylene-D-mannitol is much less reactive than hexamethylenediamine, which gives polyamides with an intrinsic viscosity as high as 2.[9] 1,6-Diamino-1,6-dideoxy-D-mannitol[2] with sebacoyl dichloride gives an insoluble, infusible polyamide.

Previous workers have also tried to prepare polymethacrylates containing sugar residues; e.g. various substituted carbohydrates containing two acrylate or methacrylate residues polymerised at 80° without the addition of a catalyst to hard, infusible, insoluble resins.[10] 3-*O*-Methacryloyl-D-mannitol pentanitrate polymerised spontaneously to a hard solid.[11] Recently 1-acrylamido- and 1-methacrylamido-1-deoxy-D-glucitol have been synthesised[12] and polymerised to give a new type of vinyl polymer containing hydrophilic sugar residues. We report now an optically active polymethacrylate containing glucose residues.



(II) (III)



(IV)

3-*O*-Methacryloyl-1,2 : 5,6-di-*O*-isopropylidene-D-glucose (II) was prepared in 68·5% yield from di-*O*-isopropylidene glucose and methacrylic anhydride in pyridine solution. Compound (II) was a colourless, viscous syrup (b.p. 120°/0·2 mm.; $[\alpha]_D$−32·2° in *sym.*-tetrachloroethane). Polymerisation of a 50% solution of compound (II) in benzene with 1% benzoyl peroxide at 80°, followed by precipitation with methanol, gave poly(3-*O*-methacryloyl-1,2:5,6-di-*O*-isopropylidene-D-glucofuranose) (III) in 57·5% yield (Found: C, 58·4; H, 7.24. $C_{16}H_{24}O_7$ requires C, 58·51; H, 7·37%), m.p. 214–218°. Polymer (III) was soluble in chlorinated hydrocarbons and benzene and was laevorotatory ($[\alpha]_D$−49·0° in tetrachloroethane). The intrinsic viscosity varied from 0·17 to 0·52 dl./g. (*c.*, 0·5 g./100 ml. tetrachloroethane; 25°) in different preparations.

The isopropylidene residues in substance (III) were removed with N hydrochloric acid to give poly(3-*O*-methacryloyl-D-glucopyranose) (IV) as a white powder in 51% yield. This novel "polysaccharide" was optically active ($[\alpha]_D$+47° in water) and strongly reducing. On heating, it charred without melting. The intrinsic viscosity of 0·17 dl./g. (*c.*, 0·5 g./100 ml. water; 25°) indicated a relatively short chain length

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A Polyvinyl Ether Containing Sugar Residues

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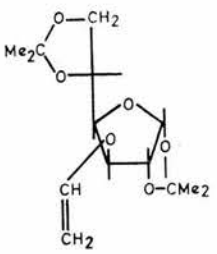
Previously we reported[1] the synthesis and polymerisation of 1,2:5,6-di-*O*-isopropylidene-3-*O*-methacryloyl-α-D-glucofuranose, and we report now the preparation and cationic polymerisation of the corresponding 3-*O*-vinyl ether (I).



(I)

This vinyl ether (I) has been prepared previously[2,3] by the high temperature reaction of acetylene on di-O-isopropylidene-glucose (DG) with a basic catalyst, but the less drastic transetherification reaction[4] with isobutyl vinyl ether has been found to give very pure monomer which can be polymerised to a high-viscosity polyvinyl ether.

DG (25 g.), pure isobutyl vinyl ether (250 ml.) and pure mercuric acetate (6·25 g.) were heated under reflux for six hours, and the cold solution was washed with 5% sodium hydroxide solution to inactivate the catalyst and remove unreacted DG. After concentration to remove isobutyl vinyl ether, the reaction solution in petrol (b.p. 60–80°) was treated with ultrasonically dispersed sodium[5] at 20° under nitrogen to decompose organomercury compounds. The residue was separated, the solution concentrated, and the syrup distilled from sodium wire to give (I) as a colourless oil (b.p. 68°/0·008 mm., n_D^{20} 1·459, $[\alpha]_D$—27° in ethanol) (Found: C, 58·6; H, 7·50. Calc. for $C_{14}H_{22}O_6$: C, 58·7; H, 7·75%). Infrared spectral analysis showed absence of hydroxyl and presence of the strong vinyl doublet at 1645, 1620 cm.$^{-1}$. The yield was about 15% based on the original weight of DG, but this could be increased to 50–75% allowing for DG recoverable from the 5% sodium hydroxide solution by extraction with chloroform.

Monomer (I) was polymerised in hexane: methylene chloride (3:1 by vol.) solution at —78°c. with the minimum amount of boron trifluoride etherate, and the product purified by solution in chloroform and reprecipitation with methanol to give the polyvinyl ether in 77% yield, m.p. 210–212°, $[\alpha]_D$+2° in *sym*-tetrachloroethane (Found: C, 58·7; H, 7·90. $(C_{14}H_{22}O_6)_n$ requires C, 58·7; H, 7·75%). The inherent viscosity $[\eta_{inh.} = c^{-1} \ln(\eta_{soln.}/\eta_{solv.})]$ was 0·65 in tetrachloroethane (*c*, 0·5 g. 100 ml.$^{-1}$; 25°). This is believed to be the first reported synthesis of a high viscosity polyvinyl ether containing carbohydrate residues.

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